Reconstructing the 1855 Cholera Epidemic in Basel Using Geographic Information Visualization

GEO 511 Master's Thesis

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Zusammenfassung

Diese Masterarbeit rekonstruiert die Choleraepidemie in Basel im Jahr 1855 mithilfe geographischer Visualisierungen. Anhand von Karten und Grafiken wurden die räumlichen und zeitlichen Muster des Choleraausbruchs sowie mögliche Einflussfaktoren wie Topographie, Flussläufe und Trinkwasserquellen analysiert.
Die in dieser Arbeit verwendeten Daten bestehen aus historischen Archivquellen zu Cholerafällen, die digitalisiert und geokodiert wurden. Weitere historische und zeitgenössische Quellen wie Volkszählungsdaten aus den Jahren 1850 und 1860, historische Karten und Geodaten zu möglichen Einflussfaktoren wurden aufbereitet, um die Umstände der Choleraepidemie zu bestimmen. Die Daten wurden in einem geografischen Informationssystem erfasst und mit Hilfe von Karten und Diagrammen visualisiert.
Insgesamt konnten 382 der 399 erfassten Cholerafälle den jeweiligen Adressen in der Stadt Basel zugeordnet werden. Die daraus resultierenden Karten zeigen eine Häufung von Cholerafällen im Kleinbasel, insbesondere an der Rheingasse in der Nähe eines Trinkwasserbrunnens. In Grossbasel traten die Fälle gehäuft vor allem im Birsig-Tal auf, während es in den höhergelegenen Teilen der Stadt weniger Fälle gab.
Die Ergebnisse reihen sich ein in die aktuelle Choleraforschung, die verunreinigtes Trinkwasser, Höhenlage und Flussnähe als Risikofaktoren für die Ansteckung mit der Cholera einstuft. Mit dieser Digitalisierung und Aufbereitung der historischen Daten können weitere Forschungen durchgeführt werden, z.B. mit Hilfe von Raumanalyse und Statistik oder der Epidemiologie.

Anmerkung: Diese Zusammenfassung wurde als Übersetzung des engl. Abstracts mit Hilfe von www.deepl.com erstellt und anschliessend überarbeitet.

Abstract

This Master's thesis reconstructs the cholera epidemic of Basel in the year 1855 by means of geographic information visualization. The spatial and spatio-temporal patterns of the cholera outbreak were analyzed using maps and graphs along with potential influencing factors such as topography, river courses, and sources of drinking water.

The data used in this thesis consist of historical archive sources on cholera cases that were digitized and geocoded. Additional historical and contemporary sources such as census data from the years 1850 and 1860, historical maps, and geodata on possible influencing factors were processed to approximate the era of the cholera epidemic. The datasets were collected in a geographic information system and were explored and visualized using maps and graphs.

In total, 382 of the 399 recorded cholera cases were assigned to their respective addresses in the city of Basel. The resulting maps revealed cholera case accumulations in Kleinbasel, especially on *Rheingasse* street in the surroundings of a drinking water well. In Grossbasel, cases occurred in clusters mostly in the Birsig river valley with fewer cases in the more elevated parts of the city.

The results stand in relation to contemporary cholera research classifying contaminated drinking water, elevation, and river proximity as risk factors in the contraction of cholera (World Health Organization 2022, Luque Fernandez et al. 2012, X. Wang and Yang 2021). With this digitization and processing of the historical data, further research can be conducted, e.g. using spatial analysis and statistics, or epidemiology.

Keywords: Cholera, Historical Data, GIS, Geographic Information System, Geographic Information Visualization, Spatial Epidemiology, Disease Mapping

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Further, I want to thank everyone who who helped me during this thesis, especially the following individuals:

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1 Introduction

Six cholera pandemics occurred in the 19^{th} century after having spread from India across the world. The 3^{rd} cholera pandemic (1846 - 1862) heavily affected Europe – including Switzerland (1854 - 1855) (Vogt 1929).

The cholera outbreak in London in the year 1854 became well known through the story of John Snow. He mapped the cholera deaths and proved his idea of waterborne disease transmission, attributing numerous deaths to a contaminated water pump. John Snow's cholera map has been revisited many times using various spatial analysis methods by researchers such as Shino Shiode (2012) and N. Shiode et al. (2015). In recent years and with the COVID-19 pandemic, researchers looked back at past pandemics and epidemics in order to better understand the origin and outcome of diseases (Staub, Jüni, et al. 2021, Staub, Floris, and Rühli 2022).

However, a similar reappraisal has not been done for the cholera outbreak in Basel in Switzerland. The cholera outbreak in Basel 1855 is very well documented but has not been reassessed using a digital approach. This serves as the main research goal of this thesis.

With the rise of the current COVID-19 pandemic, the importance of understanding the ways in which diseases transmit became visible as measures for disease prevention are more effective if the way of contagion is known (Jimenez et al. 2022). In contrast to cholera and other diseases, COVID-19 is transmitted via aerosols, i.e. an airborne transmission. Although this was not always clear, with the World Health Organization at first assuming the disease was contracted by droplets and contaminated surfaces (Jimenez et al. 2022). With the knowledge of COVID-19 being airborne, adequate disease prevention measures could be taken, e.g. wearing hygienic masks.

1.1 Motivation

1.2 Research aim

The aim of this thesis is to reconstruct the course of the 1855 cholera outbreak in Basel with the use of spatial and spatio-temporal visualizations, setting the historical resources into a geographical context.

1.3 Research gaps and research questions

1.3.1 Research gaps

Despite recent work on past pandemics and epidemics in Switzerland (Staub, Jüni, et al. 2021, Staub, Floris, and Rühli 2022), the 1855 cholera outbreak in Basel has not been studied since the 1980s. With the last piece of research in form of a licentiate thesis dating back to 1989 (Bachmann 1989), this outbreak has not been evaluated using contemporary research methods until now.

Apart from the infamous 1854 cholera epidemic in London, other outbreaks of the 19th century have been reconstructed in recent years (Schouten 2016, Scapoli et al. 2003). Broadening the view by looking into different outbreaks is crucial to get a better picture of the cholera pandemics of that era. It is important to differentiate between outbreaks, as each one occurred under particular circumstances. With recent projects such as the *Bürgerforschung Basel (BBS)* citizen science project, which emerged with the archaeological excavation of a former hospital cemetery (Hotz, Zulauf-Semmler, and Fiebig-Ebneter 2016), the reconstruction of the cholera outbreak in Basel in 1855 complements current research on 19th century Basel.

1.3.2 Research objectives and questions

With the above-mentioned research gaps, the following objectives for this thesis can be stated:

1. To digitize the historical archive data of 1855 Basel's cholera outbreak
2. To reconstruct the 1855 cholera epidemic in Basel visually
3. To describe potential causes of disease spreading in Basel 1855

Based on these research goals, this thesis aims at answering the following research questions:

1. To digitize the historical archive data of 1855 Basel's cholera outbreak
   - Q 1.1 How can historical data on the cholera epidemic in Basel 1855 be processed for further digital use?
2. To reconstruct the 1855 cholera epidemic in Basel visually
   - Q 2.1 What kind of spatial pattern do the cholera cases in Basel 1855 show?
   - Q 2.2 How does the spatial pattern vary throughout the course of the epidemic?
3. To describe potential causes of disease spreading in Basel 1855
   - Q 3.1 What factors potentially influenced the spreading of cholera?

2 Background

2.1 Cholera Now and Then

What we know today According to the World Health Organization, we are currently in the seventh cholera pandemic, which started in the year 1961 (World Health Organization 2022). With an estimated number of 2.86 million cholera cases each year leading to approximately 95'000 deaths, 1.3 billion people are at risk of catching the disease in countries where cholera is endemic (Ali et al. 2015). Ali et al. state that cholera is endemic in 69 countries, whereas the highest mortalities occur in Sub-Saharan Africa, India, Bangladesh, Haiti, and Sudan.

The transmission of cholera follows the fecal-oral route (World Health Organization 2022). The oral ingestion of food and water contaminated by *Vibrio cholerae* bacteria can lead to symptoms such as acute watery diarrhea after 12 hours to 5 days after ingestion, potentially causing severe dehydration and subsequent death (World Health Organization 2022). However, the vast majority of infected people do not develop symptoms and for those who do, mostly mild symptoms occur (World Health Organization 2022).

As the essential ways of disease transmission are known for cholera, outbreaks and further infections can be prevented by taking hygiene measures such as access to safe water and sanitation, as well as hygiene practices (World Health Organization 2022). These measures are not only important for the containment of cholera, but also for other water-borne diseases. Recent studies, both on historical and contemporary cholera epidemics, have examined what environmental factors stand in relation to the transmission of cholera, revealing what measures can be taken for additional disease prevention (X. Wang and Yang 2021, Luque Fernandez et al. 2012). Wang and Yang (2021) identified temperature, precipitation, river distance, river density, and elevation as natural influencing factors. Luque Fernandez et al. (2012) have found elevation to be a risk factor, with higher elevations yielding a lower risk for cholera infections.

Nowadays, cholera can be treated easily using an oral rehydration solution, provided that treatment is initiated in due time (World Health Organization 2022). Further, oral cholera vaccinations are essential for the prevention of cholera (World Health Organization 2022).

Cholera in the 19th century Cholera originated in the Indian Ganges Delta and lead to six global cholera pandemics during the 19^{th} century (World Health Organization 2022). Prominent cholera outbreaks of this era include but are not limited to the epidemics in London (1848 to 1849 and 1853 to 1854) (Bingham, Verlander, and Cheal 2004), in Paris 1849 (Mée 1998), and Munich 1854 (Martin 1857).

At the present time, we know a lot about cholera, but people in the 19^{th} century did not have the same understanding of disease transmission. *Vibrio cholerae* was identified in the year 1883 by Robert Koch as the bacterium responsible for cholera (Phelps et al. 2018). Before this, the miasma theory was the prevalent paradigm for explaining the transmission of cholera (Phelps et al. 2018). The miasma theory is based on the belief that bad odors from the ground are responsible for diseases, which would correspond to an airborne transmission (Vandenbroucke 2003). The counter theory of the miasma theory is contagionism, which is based on the belief that diseases are transmitted through contagion between people (Ackerknecht 2009). The miasma theory belongs to the realm of anticontagionism, i.e. the belief that diseases are not transmitted from one person to another, but rather by external factors such as environmental conditions or the living situation (Ackerknecht 2009). It was believed that the source of these miasmas was decaying animal or vegetable matter or "filth" (Jimenez et al. 2022).

In terms of cholera the miasma theory was challenged by John Snow during the London outbreaks in 1849 and later 1854, where he found the disease to be transmitted via contaminated drinking water, hence focusing on a waterborne transmission of cholera (Paneth 2004).

2.2 The use of GIS in spatial epidemiology

Spatial epidemiology studies the relationship between the spatial location of people and the occurrence of diseases (Elliott and Wartenberg 2004). It involves the use of geospatial data and cartography to analyze the distribution of diseases in space and time and to identify spatial patterns (Elliott and Wartenberg 2004, Gatrell and Löytönen 1998). Maps are an effective tool for visualizing the spread of diseases. They can help interpret data and decision-making (Nakaya 2001). In addition to this, health infrastructure can be mapped, revealing the accessibility of health services to the public (Musa et al. 2013, F. Wang 2020).

In recent years, advances in the field of geographic information science have opened up new approaches in the field of spatial epidemiology, e.g. geocoding of cases, record linkage and data integration, and spatial and spatio-temporal clustering (Kirby, Delmelle, and Eberth 2017). Spatial statistical methods that are used in spatial epidemiology include cluster analysis or ecological analysis, which aims at identifying risk factors that are associated with a particular disease, e.g. with the use of spatial regressions or geographically weighted regression (Osei 2014). However, linking a disease pattern to possible influencing factors may yield the problem of spatial autocorrelation (Osei 2014).

Although it is often assumed that John Snow was one of the first to map diseases, earlier maps exist and for example, can be found in Tom Koch's *Cartographies of Disease* (2017). Despite John Snow not being the first spatial epidemiologist, he played an important role in the 1854 London cholera outbreak and therefore will be looked at more closely in the following section.

2.2.1 John Snow's cholera map

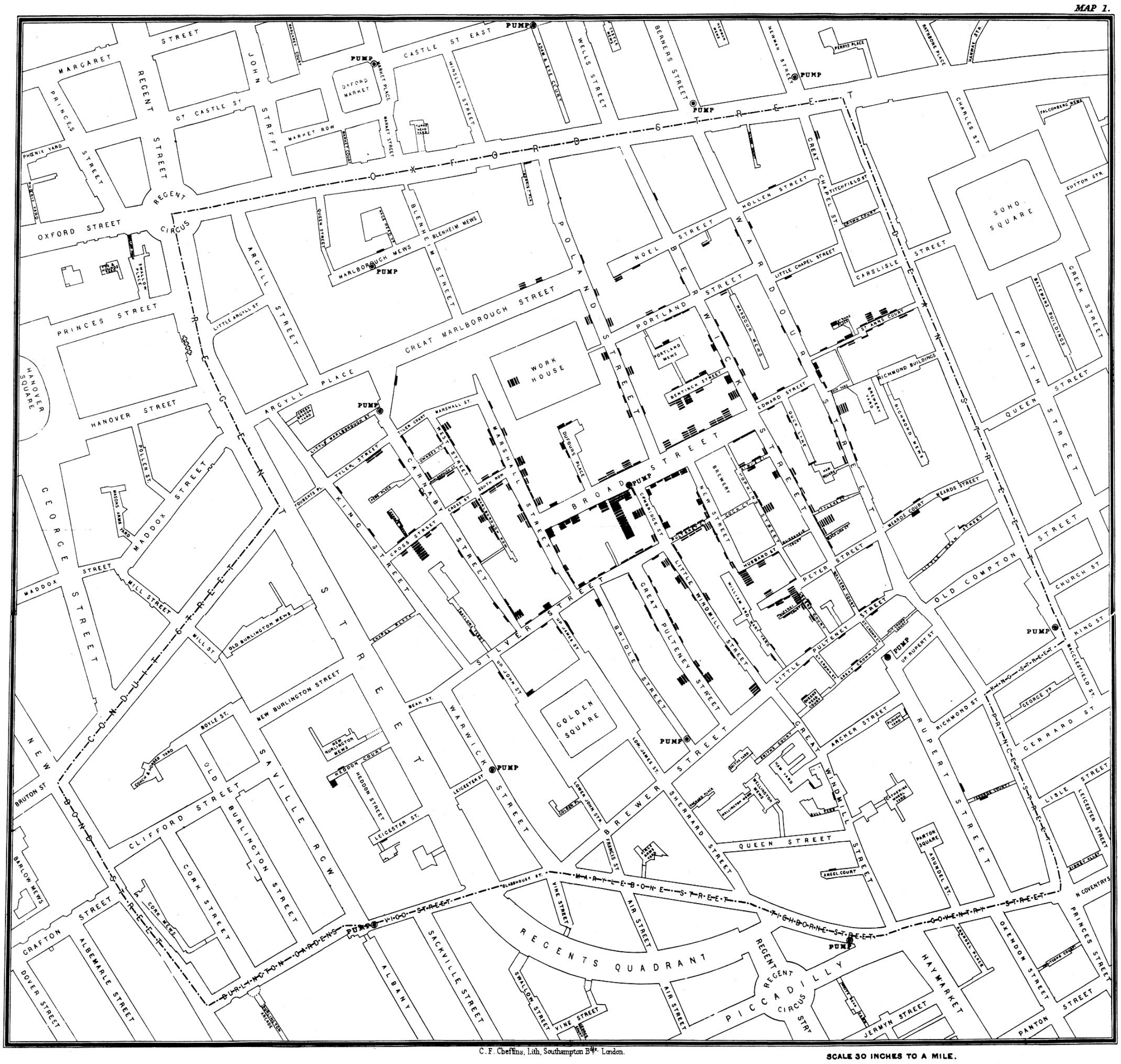


Figure 2.1: John Snow's cholera map on the outbreak in Soho, London in 1854 (Snow 1854).

In 1849, years before the infamous London cholera epidemic in 1854, John Snow questioned the miasma theory, stating that cholera was more likely to be contracted by water (Koch 2004). During the 1854 outbreak, Snow intended to verify his previous hypothesis, which resulted in the cholera map that we know today (see Figure 2.1.) (Koch 2004). Hence, the map's purpose was to communicate his findings from 1849 by showing that the cholera cases were located around the contaminated Broad Street Pump and not vice versa (Brody et al. 2000, Paneth 2004). It is a myth that John Snow found the contaminated pump by mapping the cholera cases, leading to the removal of the pump's handle and thus to the remission of the outbreak (Brody et al. 2000). This was challenged later on, as no written evidence was found in Snow's notes (McLeod 2000). Further, despite Snow's findings, local authorities in London were not convinced of John Snows theory of the waterborne transmission of cholera, as the miasma theory was present during that time (Koch and Denike 2009).

Snow's map became famous, and depending on the field of research, the story behind it and even the map itself were altered to fit the message of the respective authors, which led to myths around the work of John Snow (Koch 2004). In his paper, Tom Koch (2004) nam that map-making may not be necessarily scientific, although it may serve science, as the author decides what is mapped (Koch 2004).

2.2.2 GIS in cholera research

Snow's cholera map has been revisited several times in recent years in the context of GIScience (Koch and Denike 2009; N. Shiode et al. 2015; S. Shiode 2012). For example, Shino Shiode focused on finding the cholera area in London along the street network by looking at a network-based Voronoi diagram of the water pumps (S. Shiode 2012). In addition, his study used a network-based clumping method (S. Shiode 2012).

In another paper, Narushige Shiode and colleagues (N. Shiode et al. 2015) went further and included census data to get an understanding of how the cases were distributed compared to the population at risk (N. Shiode et al. 2015). With this approach, cases could be set in relation to the number of people living on a particular street. In this study, a Kernel Density Estimation and a cluster detection through a net scan were performed (N. Shiode et al. 2015). The authors found that high mortalities occurred around the Broad Street Pump and that the absence of a clear space-time pattern indicated a waterborne cholera transmission (N. Shiode et al. 2015).

Tom Koch (2009) questioned John Snow's approach by communicating and disseminating his findings to his peers, trying to understand why Snow was not believed at the time. By drawing Thiessen polygons around the water pumps in the area of the 1854 London cholera outbreak, Koch's outcome led to the same results as John Snow's, which is that the Broad Street Pump was very likely to have played a role in transmitting cholera during that time (Koch and Denike 2009). Caplan, Kennedy, and Neudecker (2020) used Risk Terrain Modeling to come to similar conclusions. Walford (2020) further investigated whether different demographics and socioeconomic backgrounds played a role in the use of public water pumps.

The cholera outbreak in London in 1854 has been reappraised due to its historical relevance, not least because of the myth about John Snow and the accessibility of his data. However, other studies have used GIS methods in their research of both recent and historical cholera outbreaks.

Griffiths et al. (2021) studied the cholera epidemic in Haiti, looking at cholera cases over the period between January 2015 and September 2016. With hierarchical clustering, the authors found among other things areas close to rivers and unimproved water sources, as well as urban areas near markets to be relevant risk factors in the contraction of cholera (Griffiths et al. 2021). Phelps et al. (2018) found that the short-cycle transmission of cholera through food and within households played a role in the 1853 outbreaks in Denmark and the authors link these patterns to recent cholera outbreaks in Haiti. Clustering methods were further used to identify areas at great risk of cholera in Guinea-Bissau in 2008, using the spatial scan statistic software SaTScan by Martin Kulldorff, which has also been used for different studies (Luquero et al. 2011, Kulldorff et al. 2005, Chuang et al. 2018). Spatial and spatio-temporal clustering was also performed to study endemic cholera in Matlab, Bangladesh for the time period between 1983 and 2003, suggesting that contaminated water reservoirs were the source of transmitted cholera infections. (Ruiz-Moreno et al. 2010). For the same time period in Matlab, Bangladesh, Carrel et al. (2009) studied the impact of flood control on cholera occurrence using spatial and spatio-temporal clustering with SaTScan.

Nkeki and Osirike (2013) used geographically weighted regression to study the spatial relationships between the occurrence of cholera and the water supply of houses in Nigeria in 2005.

2.3 Cholera in Switzerland

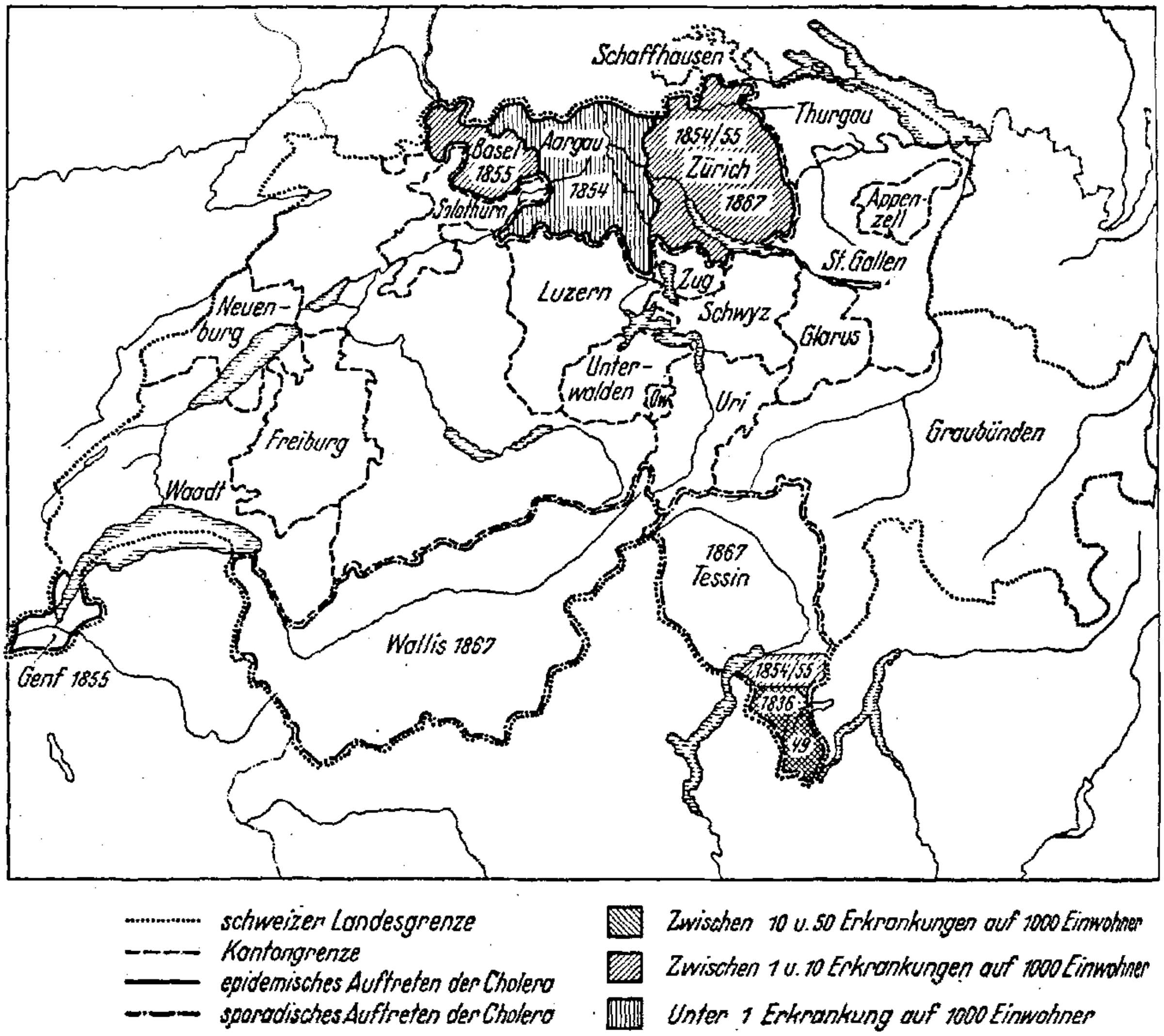


Abb. 5. Die geographische Verteilung der Cholera in der Schweiz von 1836—1867.

Figure 2.2: Map of the cholera epidemics in Switzerland from 1836 to 1867 by Ilse Teuber (Teuber 1947).

In the 19th century, cholera affected not only Basel in 1855 but also other regions of Switzerland, as can be seen in Figure 2.2 (Teuber 1947). Switzerland's first cholera outbreak in 1836 was in the canton Ticino after the disease had spread from the northern Italian region Lombardy (Teuber 1947). During this outbreak, 293 people were infected, of these 183 people died of cholera (Teuber 1947). Switzerland was affected the most during the third cholera pandemic when again the canton of Ticino was affected in the year 1849, although this time not as severely, followed by bigger outbreaks in 1854 and 1855 (Teuber 1947). In 1854, further outbreaks occurred in the canton of Aargau with occasional cases spreading to the neighboring canton of Zurich (Teuber 1947).

In 1855, apart from Ticino, further cantons were affected by cholera, i.e. Basel-Stadt, Basel-Land, Zurich, and Geneva (Teuber 1947). In Basel-Stadt, where especially the city of Basel will be of interest in this thesis, 399 people contracted cholera, of these 205 people died (Teuber 1947). The toponym *Basel* is referred to the city of Basel in this thesis. In total, in Basel-Land, 504 cholera cases were counted, leading to 210 deaths (Teuber 1947). The cholera outbreak in Geneva was less severe in relation to its bigger population, where 92 people were infected and 50 died, respectively (Teuber 1947). In three municipalities of the canton of Zurich (Stadt Zürich, Fluntern, and Unterstrass), 101 cholera cases were counted and 44 people died (Teuber 1947).

In 1867, the first cholera cases were again found in Ticino, with 192 cases and 112 respective deaths (Teuber 1947). The 1867 cholera epidemic in the canton of Zurich was the biggest so far, with 684 infections and 481 deaths caused by cholera (Teuber 1947).

Teuber remarks that the regions, where cholera epidemics took place, were all located in the border area, and most outbreaks took place near waterbodies such as lakes or rivers (Teuber 1947). In regard to the season all epidemics mainly fell into the summer months of July, August, and September (Teuber 1947).

2.4 Cholera epidemic in Basel in the year 1855

2.4.1 Mid-19th century Basel

Today, Basel is the third biggest city in Switzerland with about 196,600 local residents (Bundesamt für Statistik 2022). Basel is situated in the northwest of Switzerland, bordering France and Germany. Mid-19^{th} century Basel counted ca. 29,700 inhabitants and was shaped by early industrialization (Ludwig De Wette 1856). With a rapidly growing population, the hygienic situation at that time was bad and sewage disposal was uncoordinated (Haefliger 1984).

The majority of the population lived in the inner city parts of Basel, which is divided into two main parts: Grossbasel, which is situated on the southwestern side of the river Rhein, and Kleinbasel on the northeastern riverside, as can be seen in the Situation map (1862) in Figure 2.3 (Loeffel and Falkner 1862). Due to its historical growth since before the Middle Ages, Grossbasel was further divided into the inner city core and its adjacent districts called *Bänne* (Degen and Sarasin 2017).

The following sections address historical sources to get a more detailed understanding of the living situation in Basel and its cholera epidemic of 1855.

Figure 2.3: Situation map of Basel, created between 1857 - 1859 by L. H. Loeffel (1862).

2.4.2 Cholera report by Ludwig De Wette (1856)

In the report *Bericht an Löbl. Cholera-Commission über den Verlauf der Cholera im Jahre 1855*, physician Ludwig De Wette reconstructs the cholera outbreak of Basel in 1855 (Ludwig De Wette 1856). He addressed the cholera commission of Basel Stadt and signed with the date of December 12, 1855 (Ludwig De Wette 1856). The report describes the early spread of cholera, what measures the authorities imposed and includes a thorough description of the cholera cases in terms of where they occurred, and what demographic groups were at risk (Ludwig De Wette 1856). The written report is supplemented by tables where cholera cases were aggregated into these subdivisions to make the data more approachable and to make assumptions about the potential influencing factors. Following, the main points of the report are captured to get an understanding of how a contemporary witness reviewed the cholera epidemic in Basel in 1855.

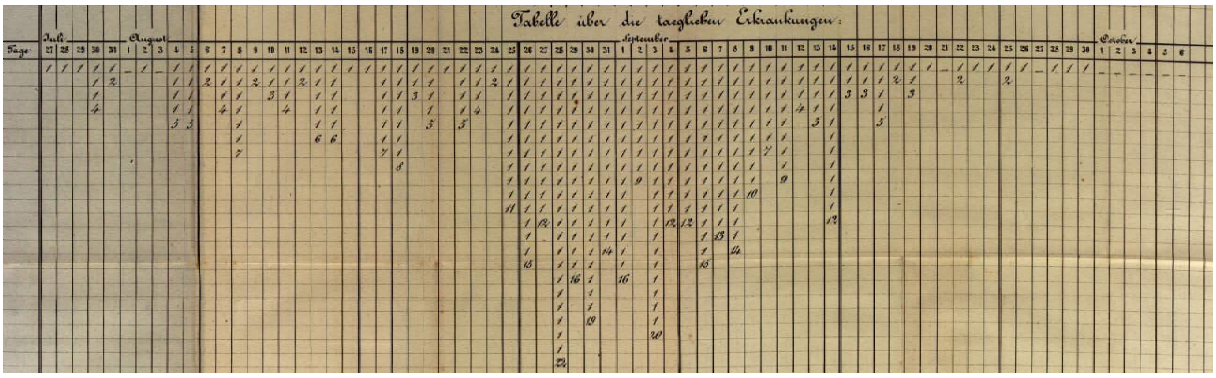


Figure 2.4: *Tabelle über die taeglichen Erkrankungen.* List of cholera cases per day during the cholera outbreak in Basel, 1855 (Ludwig De Wette 1856).

The first cholera case of the outbreak in 1855 in Basel occurred on July 27 after the said person had traveled from the Alsatian city Mulhouse, where he presumably had been infected with cholera, to Basel (Ludwig De Wette 1856, p. 5). The following few cases of the epidemic could be attributed to the first infection due to a shared place of work and subsequent contagions from these respective cases are described (Ludwig De Wette 1856, p. 5). Ludwig De Wette remarks that a pit latrine (*Abtrittgrube*) near an infected person's house had been overfilled and that it was situated between the hillside and a house near *Steinenthor 193* (Ludwig De Wette 1856, p. 5). This house evolved into a cholera hotspot (Ludwig De Wette 1856, p. 5). Basel's authorities imposed the disinfection of places where infected people had been staying, i.e. by cleaning the rooms with chlorine vapors or the disinfection of latrines using chlorinated lime or iron vitriol, as well as changing and disinfecting the bedding and clothing of the sick (Ludwig De Wette 1856, p. 8).

De Wette states, that cholera primarily infected people of the working class, which led to specific measures for targeting this group during work by sending them home when they appeared sick (Ludwig De Wette 1856, p. 10). They were encouraged not to drink too much water, but rather hot beverages such as tea (Ludwig De Wette 1856, p. 10). Further, the disinfection of the latrines was advised (Ludwig De Wette 1856, p. 10). The authorities considered that the best form of cholera treatment was preventing the spread of the disease in the first place (Ludwig De Wette 1856, p. 11). The measures that were taken relied on the spread of cholera by contagion and hence healthy people were removed from the houses with infected individuals and would be brought to the casern which was repurposed for this situation. People with cholera were removed from their houses and taken to the hospital (Ludwig De Wette 1856, p. 13). Especially healthy residents of the highly affected houses on *Rheingasse* and adjacent streets were evacuated and brought to the *Klingenthal* casern, whereby authorities intended to contain the movement of these residents to curb the further spread of cholera throughout the city (Ludwig De Wette 1856, p. 15).

Ludwig De Wette states, that cases numbers were not accurate as only severe cases were reported, and mild symptoms of cholera (*Cholerine*) were not considered as cholera cases (Ludwig De Wette 1856, p. 25). Hence, the data do not show the whole picture of the epidemic (Ludwig De Wette 1856, p. 25). However, remarks about cholera case numbers with respect to the citizenry, residency location, date of the disease, and meteorological circumstances, including other possible influencing factors were made (Ludwig De Wette 1856, p. 25).

In total, 399 cholera cases were counted, of which 387 cholera cases belonged to the canton of Basel Stadt (Ludwig De Wette 1856, p. 25). Additional numbers can be seen in Table2.1.

Table 2.1: Cholera case numbers for different administration units (Ludwig De Wette 1856).

Extent	Number of cholera cases	Number of cholera-related deaths	Population (March 1850)	Morbidity (Cholera cases per population)
Canton of Basel Stadt	387	203	29,698	1.303%
Basel Stadt without Riehen and Kleinhüningen	382	200	27,313	1.39%
City of Basel without Bänne	336	174	24,399	1.34%
Bänne	45	27	2,914	1.57%

Age Physician De Wette analyzed the age distribution of the cholera cases and their respective proportions of death, stating that especially small children were at risk to catch cholera and likely to die (Ludwig De Wette 1856, p. 28-29). In the category of 60 years and older, almost all infected persons died (Ludwig De Wette 1856, p. 28-29). Comparing the age groups, most infections occurred in the group of 20 to 30 year olds, however, with considerably low mortalities, as described in Ludwig De Wette 1856, p. 31.

Social aspects Considering social aspects, the author states that the profession of the infected men was of no particular influence, although low case numbers occurred in factories where employers were advised to follow measures against contagion (Ludwig De Wette 1856, p. 33). Differences in case numbers were countered with operating conditions, i.e. whether employees worked outdoors or not (Ludwig De Wette 1856, p. 33). Concerning the living situation of the infected, boarders (*Kostgänger*), and individuals living in a family bond counted many cholera cases (Ludwig De Wette 1856, p. 34). In addition to this, the report states that Basel citizens (0.55%) were affected less by cholera than other Swiss citizens (1.55%) and foreigners (1.8%) (Ludwig De Wette 1856, p. 35).

Districts The place of residence was looked at on the district level (*Quartier*), although De Wette states that this subdivision of Basel into districts is inappropriate, as houses on the same street may belong to different districts despite their proximity (Ludwig De Wette 1856, p. 36). This resulted in some houses lying in the inner city being counted to surrounding districts (Ludwig De Wette 1856, p. 36).

Dr. De Wette notes, that the inner-city district counted more cholera cases than the surrounding suburban (*Vorstädte*) districts, despite their similarity in terms of population size, wealth and housing situation (Ludwig De Wette 1856, p. 36). It is stated that the suburban *Vorstädte* districts are located mostly on an open plain with draining, gravelly subsoil and that streets are broader, with more space between the lines of houses (Ludwig De Wette 1856, p. 36). In De Wette's report, the *Vorstädte* area includes the districts *St. Johann*, *Spahlen*, *Steinen*, *Aeschen* and *St. Alban*, although the understanding of the districts' extent is different from the official segmentation, as found in Staatsarchiv Basel-Stadt 1855 (Ludwig De Wette 1856).

The *St. Albanthal* district in the east was not affected by cholera, with latrines entering into the two river branches of the rapid-flowing *St. Albanteich* canal and most houses were populated by fewer people than in the other districts, whereas these houses were situated at higher elevations than the canal (Ludwig De Wette 1856, p. 36). Other parts of the city were not affected either, although no further explanation for this was found in Ludwig De Wette 1856, p. 37.

Sewage The report draws attention to the different ways of sewage disposal, i.e. whether feces from latrines were collected in pit latrines (*Abtrittgrube*) or whether they were washed away with water in a latrine gully (*Abtrittdole*) (Ludwig De Wette 1856, p. 37). Pit latrines were prevalent in the suburban *Vorstädte* and in a few parts of the inner city, whereas this way of sewage disposal was considered malodorous (Ludwig De Wette 1856, p. 37). However, it was technically possible to empty and sterilize the pits (Ludwig De Wette 1856, p. 37). In contrast, the *Abtrittdolen* gullies were not cleaned sufficiently (Ludwig De Wette 1856, p. 37). Disinfection was not practicable over longer distances, and a lack of water impeded washing away the feces (Ludwig De Wette 1856, p. 37). This way of sewage disposal was prevalent in *St. Albanthal* and *Birsigtheil* in the suburbs, as well as in the inner city district of Grossbasel *Stadt* (Ludwig De Wette 1856, p. 37).

De Wette raised the question of whether pit latrines in the higher-elevated parts of the inner city had an influence on lower-elevated houses due to the drainage through the soil into lower areas, i.e. in the case of the pit latrines on *Adelberg* street (more commonly

Figure 2.5: Photograph of the Birsig river, ca. 1886 (Staatsarchiv Basel-Stadt 1886).

referred to as *Nadelberg*, see Rebmann 2010), possibly draining into the lower *Schneidergasse* street (Ludwig De Wette 1856, p. 37-38). Ludwig De Wette further mentions, that in the inner city of Grossbasel most houses were situated near the hillsides and only a few in close proximity to the Birsig river (Ludwig De Wette 1856, p. 38).

Kleinbasel In comparison to the aforementioned situation in Grossbasel, Kleinbasel, which is the part of Basel situated north of the river Rhein, was much more severely affected by cholera during the outbreak in 1855 (Ludwig De Wette 1856, p. 38). The two districts in Kleinbasel showed higher morbidities than in Grossbasel, in the *Bläsi-Quartier*, 2.54 % of the population got infected with cholera during the outbreak and in the *Riehen-Quartier* even 4.05 % (Ludwig De Wette 1856, p. 38).

Reasons for disease transmission In his report on the cholera outbreak, De Wette looks for the reasons why cholera spread in Basel and why the Kleinbasel districts *Riehen-Quartier* and *Bläsi-Quartier* were affected this severely (Ludwig De Wette 1856, p. 39). He considered the class of the residents, and the low rents due to neglected housing, leading to poor people living in these houses that according to De Wette, often lacked latrines (Ludwig De Wette 1856, p. 39). He further brings up the soil conditions (gravel in Kleinbasel), the proximity to the river Rhein and the dyke with its branches flowing through Kleinbasel (Ludwig De Wette 1856, p. 39). During the months of May to August, the water level of the Rhein was high and the feces of the latrine gullies of the *Rheingasse* in the *Riehen-Quartier* district could therefore not be flushed into the Rhein (Ludwig De Wette 1856, p. 40). With the impediment of the water flow in the gullies, De Wette mentions "harmful effluvia" being emitted, especially during the dry summer months (Ludwig De Wette 1856, p. 40). He finds that fewer cholera cases occurred in the more elevated streets above *Rheingasse*, where water flowed more rapidly (Ludwig De Wette 1856, p. 40).

Meteorology De Wette tried to set the course of the cholera outbreak in the context of meteorological factors such as atmospheric pressure, air temperature, wind, general weather, and ozone level (Ludwig De Wette 1856, p. 41). He made a connection between cholera cases per day and air temperature (Ludwig De Wette 1856, p. 42). Higher temperatures correlated to higher numbers of cholera cases (Ludwig De Wette 1856, p. 42). Apart from the temperature itself, he mentions that on hotter days, people would be thirsty and would hence drink more water, as well as that the air would be more prone to transmit diseases (Ludwig De Wette 1856, p. 42).

2.4.3 General report of the cholera committee (1856)

Apart from the report by Ludwig De Wette, an additional general report of the cholera committee (*General-Bericht des Cholera-Ausschusses an den E. Kleinen Rath*) was written, addressing the mayor of Basel and other authorities (L. De Wette, Heimlicher, and Bischoff 1856). The cholera committee consisted of the above-mentioned physician Ludwig De Wette, I. Heimlicher, and G. Bischoff. The report provides additional information on what measures were taken in terms of the containment of cholera (e.g. disinfection and the relocation of the sick and healthy), but also what hygienic actions were taken after the epidemic, giving an insight on what the authorities believed to be important factors in the spread of cholera (L. De Wette, Heimlicher, and Bischoff 1856). The authors identified six main factors to be the river Birsig, street cleaning, especially in terms of sewage disposal, the condition of the gullies, the public latrines and pissoirs, malodorous industries, and food (L. De Wette, Heimlicher, and Bischoff 1856, p. 27). Some of these factors have been addressed in the previous report by De Wette, but further attempts to explain the disease pattern are worth looking at (Ludwig De Wette 1856).

The Birsig river and its above channeled-off branch called Rümelinbach played an important role in the sewage disposal in Grossbasel (L. De Wette, Heimlicher, and Bischoff 1856, p. 28-32). The authors state that the insufficient discharge of sewage (and with this also feces) as the main factor in the spread of cholera was "scientifically recognized" and that a further cholera outbreak only months later would not be impossible (L. De Wette, Heimlicher, and Bischoff 1856, p. 35). The Rümelinbach channel was used for sewage disposal rather than for industrial purposes, which proved to be convenient due to its rapid current (L. De Wette, Heimlicher, and Bischoff 1856, p. 55).

Kleinbasel Concerning the sewage disposal, the authors remark on the bad conditions of the streamlets and flushing of the latrines in Kleinbasel, especially in the heavily-affected streets *Rheingasse* and *Utengasse* (L. De Wette, Heimlicher, and Bischoff 1856, p. 60). However, not only the sewage disposal but also the latrines were a problem, with one latrine on the upper *Rheingasse* being used by over 50 people (L. De Wette, Heimlicher, and Bischoff 1856, p. 129)

Role of drinking water Concerning groceries, contaminated drinking water was considered to play a role in the cholera outbreak, as seen in the following text excerpt:

> *Als ein Lebensmittel, dessen Einfluß auf die Cholera, wie auf andere Krankheiten kaum hoch genug anzuschlagen ist, müssen wir das Trinkwasser ansehen. [...] Anzuführen aber ist, daß wir den Brunnen an der Rheingasse schließen ließen, weil in dem Wasser sich positive Spuren davon zeigten, daß die Abtritte der höhern Gegend der Utengasse und vielleicht sogar der Rebgasse nicht ohne Einfluß darauf sind, ein Einfluß, der in gewöhnlicher Zeit als gleichgültig mag angeschlagen werden, der aber weitere Untersuchungen auf diesem Gebiet als jedenfalls der Mühe werth erscheinen läßt. Obige Spuren haben sich durch chemische Untersuchung ergeben, während sich microscopisch Nichts nachweisen ließ.*

(General-Bericht des Cholera-Ausschusses an den E. Kleinen Rath 1856, p. 96)

The main message of this quotation is, that the authorities closed a well on Rheingasse street, as traces of contamination were found, presumably coming from the more elevated streets of *Utengasse* or *Rebgasse* (L. De Wette, Heimlicher, and Bischoff 1856, p. 96). These traces were found through "chemical investigations", however, more precise information on this investigation is not available (L. De Wette, Heimlicher, and Bischoff 1856, p. 96). The authors add, that in the previous year, the well water in the cities Aarau and Neudorf was also attributed to disease transmission (L. De Wette, Heimlicher, and Bischoff 1856, p. 96-97).

2.4.4 Further reappraisals of the cholera outbreak in Basel in 1855

Besides the above-mentioned two primary sources, the cholera outbreak in Basel in 1855 has been revisited in the past. The most extensive reconstruction was written by Michael

Bachmann in form of a licentiate thesis of the University of Basel in the field of history (Bachmann 1989). Bachmann's thesis comprises a thorough literature review of the outbreak in 1855 as well as cholera-related topics from 1831 to 1855 (Bachmann 1989). The literature review of Bachmann is a valuable addition to the cholera reports by Ludwig De Wette and L. De Wette, Heimlicher, and Bischoff 1856 as it looks back at the aftermath of the cholera epidemic of the year 1855 in a wider temporal horizon. He states that the water supply was not improved until 40 years later, as the connection between cholera and the water supply was not known at the time (Bachmann 1989).

From a geographer's perspective, it is interesting to see that Bachmann mapped the cholera cases to visualize their respective locations on a map, which can be seen in Figure 2.6. The cholera cases are visualized by small circles, corresponding to addresses where cholera occurred, whereas the color of the circles indicates how many people were infected at one address (Bachmann 1989). Bachmann further explains how the cholera cases were assigned to their respective addresses (Bachmann 1989). The cholera cases were mapped on the Situation map of 1862 (see Figure 2.3), although addresses had to be converted to their old format, as the house numbering system changed in 1860 between the cholera outbreak in 1855 and the publication of the Situation map of 1862 (Bachmann 1989, Haefliger 1984).

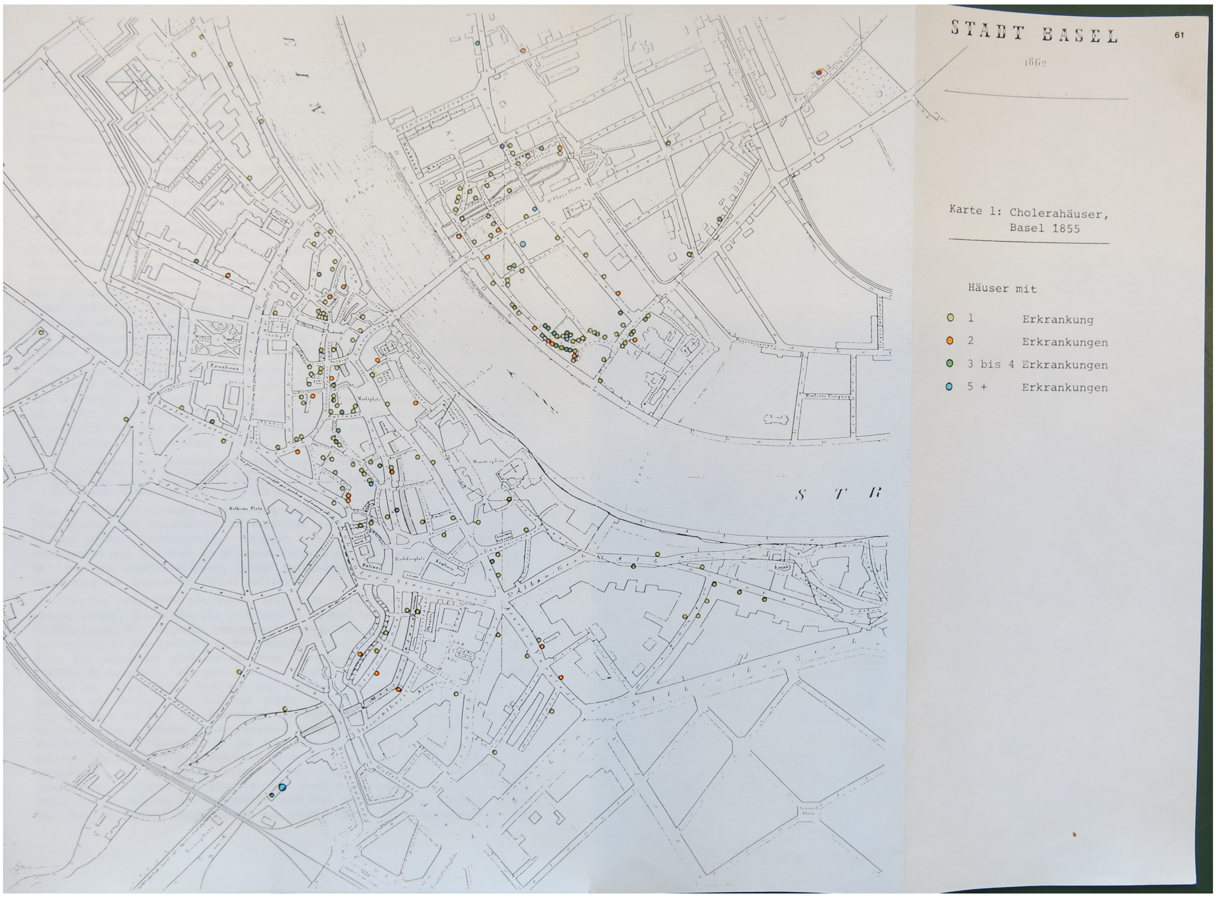


Figure 2.6: *Cholerahäuser, Basel 1855.* Map of the cholera outbreak in Basel in 1855, created by Markus Bachmann 1989.

The cholera outbreak in Basel in 1855 had also been reappraised by others prior to Bachmann (1989), e.g. by Otto Vogt who visualized the outbreak by drawing a graph of the number of cases per day or per age group, again mapping the cholera cases, which is shown in Figure 2.7. This map was created prior to the map of Markus Bachmann above, and both maps share similarities, especially as both authors used the Situation map by Löffel (1862) as a background, with circles representing the cholera cases' addresses.

Water wells Concerning the relevance of the wells for drinking water, Markus Haefliger remarks that the groundwater wells (*Sodbrunnen*) were often situated in the backyard near the pit latrines (Bachmann 1989, p. 153). He notes that for both the cholera epidemic in 1855 and the typhus outbreak in 1865, the center of the city was affected the most, both due to high population densities and also due to the topography, which enabled the creation of these *Sodbrunnen* wells in these areas in the first place (Bachmann 1989, p. 153). Later, the unsanitary condition of the *Sodbrunnen* wells led to their shutdown and the subsequent modernization of the water supply in Basel (Bachmann 1989, p. 154). Haefliger states that the usage of groundwater wells as a source of drinking was an essential risk in terms of cholera and typhus epidemics in Basel (Bachmann 1989, p. 154). However,

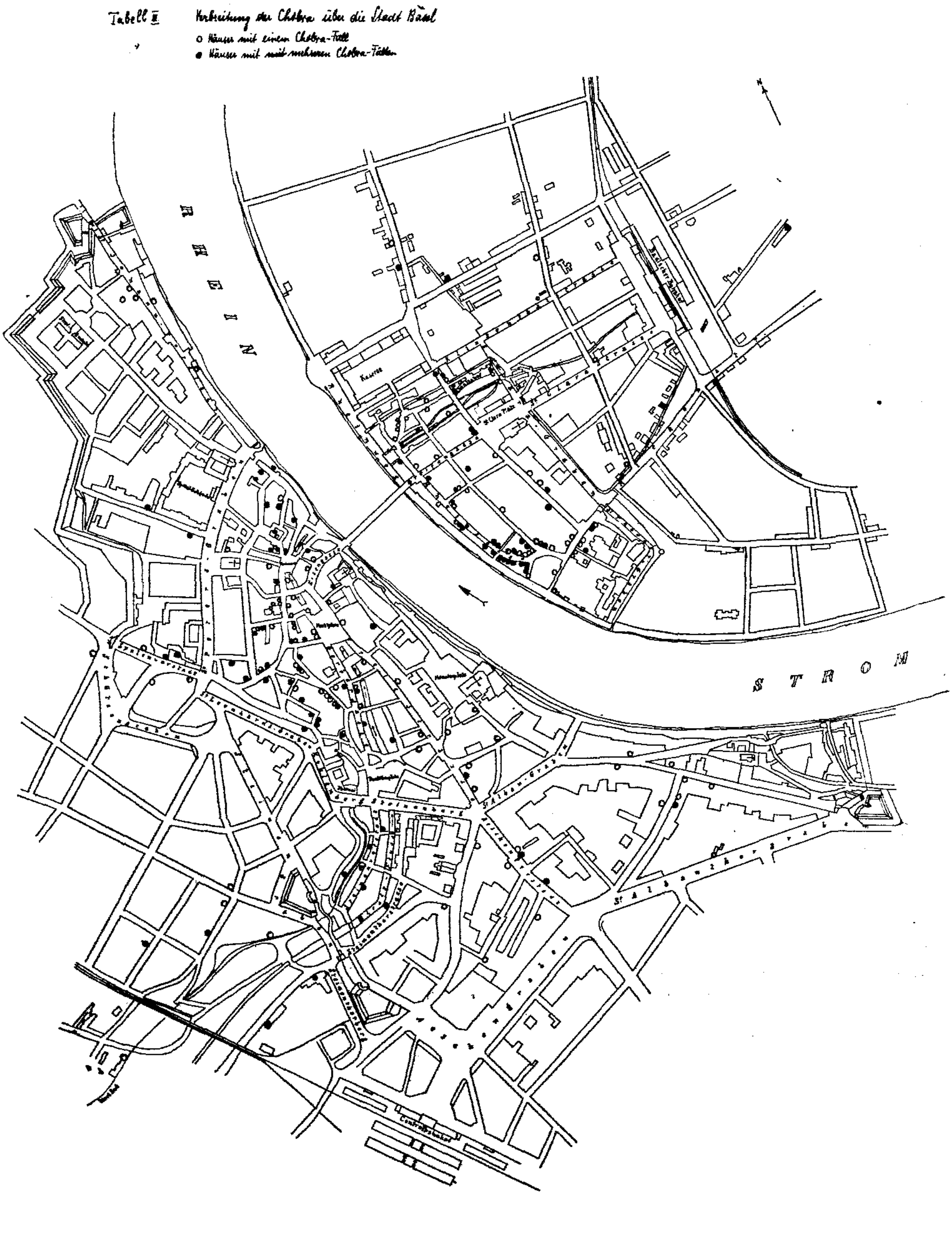


Figure 2.7: *Verbreitung der Cholera über die Stadt Basel.* Map of the cholera outbreak in Basel in 1855, created by Otto Vogt 1929.

authorities were not aware of this risk or did not mention the role of groundwater wells, e.g. in the *Generalbericht des Cholera-Ausschusses* mentioned above (L. De Wette, Heimlicher, and Bischoff 1856). The *Sodbrunnen* groundwater wells were indeed not mentioned in the report, however, the authors were aware of the potential influence of contaminated drinking water, as was discussed in the quotation above (L. De Wette, Heimlicher, and Bischoff 1856, p. 96).

3 Methods

3.1 Data sources, preparation and processing

The data that were included in this thesis consist of data on the cholera cases of the outbreak in 1855, historic maps of Basel, census data from 1850 and 1860, and geographic data in form of a digital terrain model (DTM). Based on these data sources and other geodata available online, datasets were created to match the era of mid-19th century Basel, following this thesis' research goals. Data sources and their respective manipulations are described in the following chapter.

3.1.1 Cholera case data

The dataset on the cholera cases that was created in this thesis originates from two different sources: Firstly, a report of all cholera cases that occurred during the cholera outbreak in Basel in 1855 (Staatsarchiv Basel-Stadt 1855) and secondly, a list of cholera cases included in Ludwig De Wette's *Bericht an Löbl. Cholera-Commission über den Verlauf der Cholera im Jahre 1855* (Ludwig De Wette 1856).

Data sources The report of the 1855 cholera cases in *Controlle saemtlicher Cholerafälle im Jahre 1855* from the Staatsarchiv Basel-Stadt (engl. National Archives Basel-Stadt) consists of a historic collection of the cholera cases in Basel Stadt in 1855 and is available in tabular format (Staatsarchiv Basel-Stadt 1855). The source consists of digital photographs of hand-written tables. An exemplary excerpt of the first page is shown in Figure 3.1. It comprises the patient's case number (*No*), name (*Geschlechts & Rufname*), hometown (*Heimath*), age (*Alter*), profession (*Beruf*), residential address (*Wohnung*) consisting of street name (*Strasse*) and house number (*No*), the date of the start of the disease (*In Behandlung*) and whether the patient stayed at a private location (*Privathäuser*) or at the hospital (*Spital*). Further, either the date of recovery (*Genesen*) or the date of death (*Gestorben*) is indicated. Additionally, notes (*Anmerkungen*) were taken sporadically.

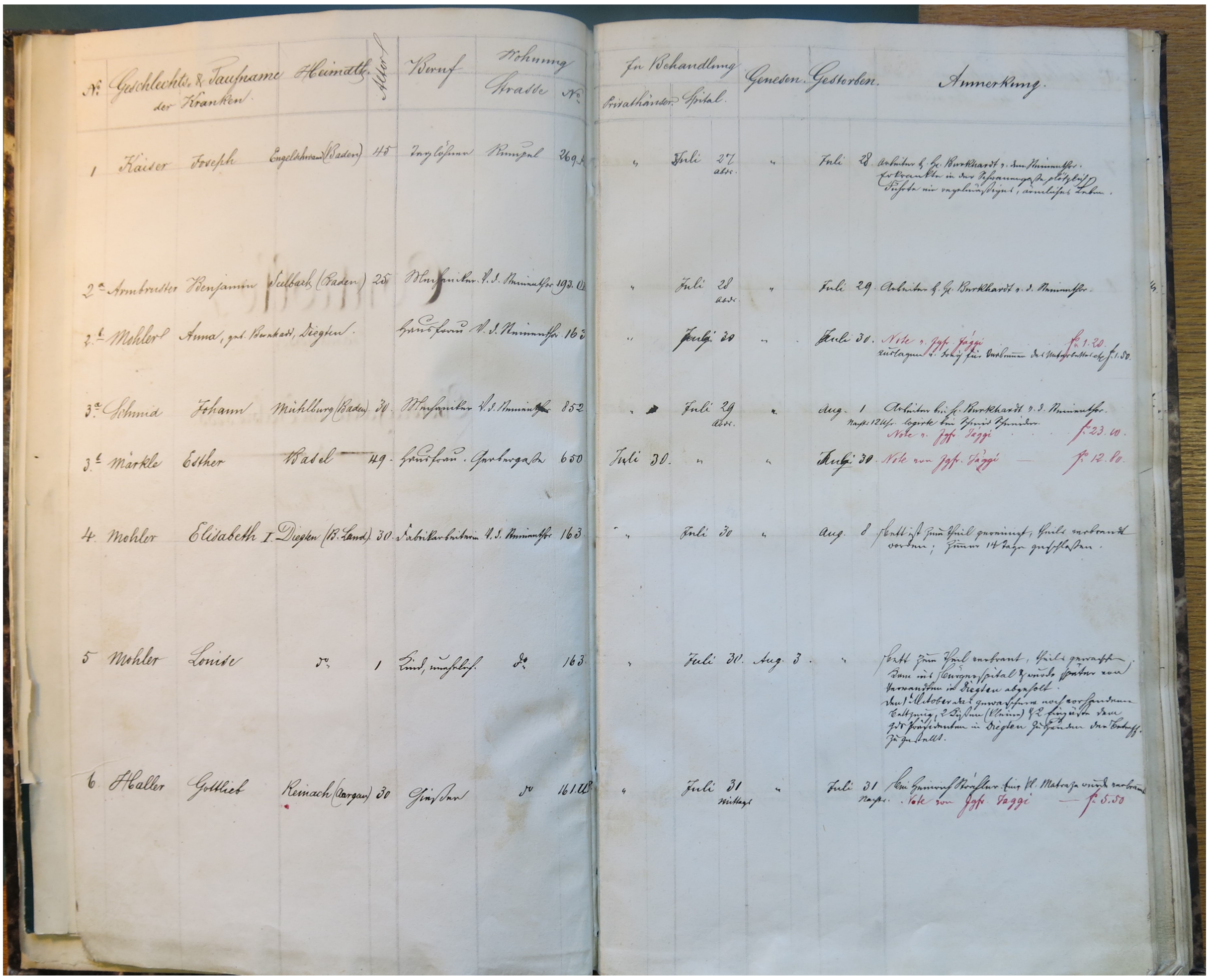
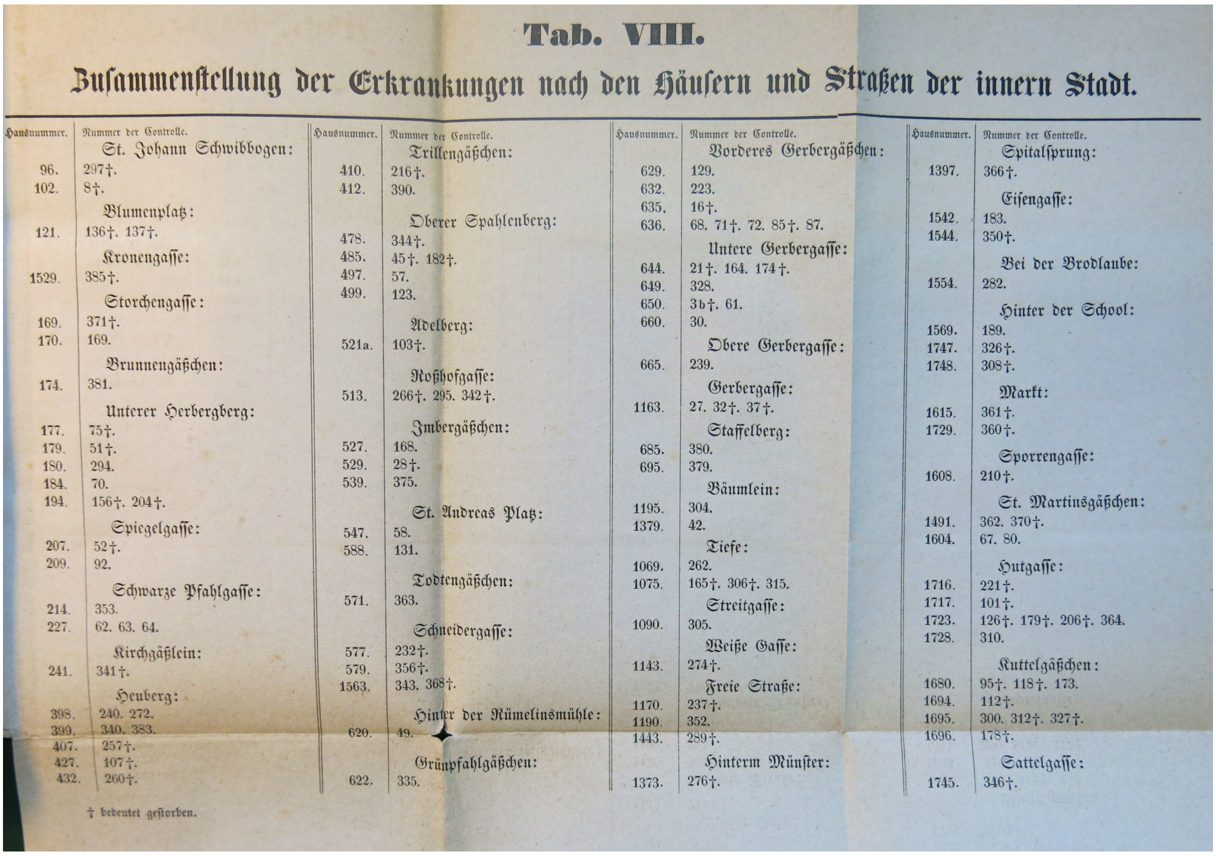


Figure 3.1: Excerpt of the report on cholera cases in Basel 1855 (Staatsarchiv Basel-Stadt 1855).

Apart from the thorough reappraisal of the cholera outbreak in Basel 1855 in the form of written text, De Wette's *Bericht an Löbl. Cholera-Commission über den Verlauf der Cholera im Jahre 1855* provides a list of each cholera case's control number (*Nummer der Controlle*), district, street name, and house number (*Hausnummer*) of the majority of recorded cholera cases and whether the individual had died from cholera (*†*)(Ludwig De Wette 1856). It is assumed that De Wette used the report of the cholera cases above for this list due to their strong congruence. An exemplary excerpt of the table can be seen in Figure 3.2.

Data preparation and processing To use these data, a transcription into tabular form was done. For this, the cholera cases of Ludwig De Wette's report were manually transcribed into a Microsoft Excel sheet. Afterward, the handwritten *Controlle saemtlicher Cholerafälle im Jahre 1855* tables were matched by linking the cases to their respective control numbers. Subsequently, these additional attributes were transcribed into the Microsoft Excel sheet.



Tab. VIII.

Zusammenstellung der Erkrankungen nach den Häusern und Straßen der innern Stadt.

Hausnummer.	Nummer der Controlle.
	St. Johann Schwibbogen:
96.	297†.
102.	8†.
	Blumenplatz:
121.	136†. 137†.
	Kronengasse:
1529.	385†.
	Storchengasse:
169.	371†.
170.	169.
	Brunnengäßchen:
174.	381.
	Unterer Herbergberg:
177.	75†.
179.	51†.
180.	294.
184.	70.
194.	156†. 204†.
	Spiegelgasse:
207.	52†.
209.	92.
	Schwarze Pfahlgasse:
214.	353.
227.	62. 63. 64.
	Kirchgäßlein:
241.	341†.
	Heuberg:
398.	240. 272.
399.	340. 383.
407.	257†.
427.	107†.
432.	260†.
	Trillengäßchen:
410.	216†.
412.	390.
	Oberer Spahlenberg:
478.	344†.
485.	45†. 182†.
497.	57.
499.	123.
	Adelberg:
521a.	103†.
	Roßhofgasse:
513.	266†. 295. 342†.
	Imbergäßchen:
527.	168.
529.	28†.
539.	375.
	St. Andreas Platz:
547.	58.
588.	131.
	Todtengäßchen:
571.	363.
	Schneidergasse:
577.	232†.
579.	356†.
1563.	343. 368†.
	Hinter der Rümelinsmühle:
620.	49.
	Grünpfahlgäßchen:
622.	335.
	Vorderes Gerbergäßchen:
629.	129.
632.	223.
635.	16†.
636.	68. 71†. 72. 85†. 87.
	Untere Gerbergasse:
644.	21†. 164. 174†.
649.	328.
650.	3b†. 61.
660.	30.
	Obere Gerbergasse:
665.	239.
	Gerbergasse:
1163.	27. 32†. 37†.
	Staffelberg:
685.	380.
695.	379.
	Bäumlein:
1195.	304.
1379.	42.
	Tiefe:
1069.	262.
1075.	165†. 306†. 315.
	Streitgasse:
1090.	305.
	Weiße Gasse:
1143.	274†.
	Freie Straße:
1170.	237†.
1190.	352.
1443.	289†.
	Hinterm Münster:
1373.	276†.
	Spitalsprung:
1397.	366†.
	Eisengasse:
1542.	183.
1544.	350†.
	Bei der Brodlaube:
1554.	282.
	Hinter der School:
1569.	189.
1747.	326†.
1748.	308†.
	Markt:
1615.	361†.
1729.	360†.
	Sporrengasse:
1608.	210†.
	St. Martinsgäßchen:
1491.	362. 370†.
1604.	67. 80.
	Hutgasse:
1716.	221†.
1717.	101†.
1723.	126†. 179†. 206†. 364.
1728.	310.
	Kuttelgäßchen:
1680.	95†. 118†. 173.
1694.	112†.
1695.	300. 312†. 327†.
1696.	178†.
	Sattelgasse:
1745.	346†.

† bedeutet gestorben.

Figure 3.2: Excerpt of De Wettes' report on cholera in Basel 1855 (Ludwig De Wette 1856).

The complete collection of case numbers was subsequently geocoded using the residential addresses. For the geocoding of the residential addresses, the contemporary address names were not compatible with the indicated addresses of the cholera cases since the house numbering system was different from now. These differences are described in Hotz, Schumacher, et al. 2015.

To match the addresses, the attributes house number and district were essential in this historical address system. The cadastre dataset containing the historical addresses and their respective locations is not publicly available. Andreas Kettner, the consultant of the land registry of the canton Basel Stadt (*Grundbuch- und Vermessungsamt Basel Stadt*) matched the previously transcribed addresses of the cholera cases and provided the geocoded point dataset in shapefile format. Cholera case points belonging to the same address were assigned the same coordinates.

The attributes of the resulting point dataset comprise street name, house number, district, and control number of the two sources, respectively (Staatsarchiv Basel-Stadt 1855, Ludwig De Wette 1856). Personal information of the infected includes the attributes first and last name, sex, age, and profession. Regarding information on the cholera infection, the location of therapy (at home or at a hospital), the start and end dates of the disease, the calculated duration of the disease until recovery or death, which is further indicated, and the week in which the outbreak happened (starting at week 1). Additionally, the count of how many infections happened at one address (overall and for each week) is shown. Spatial calculations were done using other datasets, such as extracting the elevation of a cholera case point (Bundesamt für Landestopografie swisstopo 2022), the district name and number of the district geometry dataset, and the division into urban and rural Grossbasel and Kleinbasel.

3.1.2 Situation map 1862

To get an understanding of the spatial extent of Basel, the base map which was used in this thesis is the situation map 1862 of Basel city (*Situationsplan 1862*) (Loeffel and Falkner 1862). It was created between 1857 and 1859 by the surveyor L. H. Loeffel (Kanton Basel Stadt 2022). For the outer districts, map material by the surveyor R. Falkner was included (Kanton Basel Stadt 2022).

The situation map was finally printed in the year 1862 and was georeferenced and made publicly available for digital use by the canton of Basel Stadt. The map was originally mapped at a 1:2000 scale and printed as a lithograph. With its high spatial resolution, small details such as buildings, streets, river courses, and wells are mapped in this issue. The map was first introduced in the Background section and is depicted in Figure 2.3.

Due to the creation period between 1857 and 1859 and the map's fitting spatial extent, it is the most suitable of the available historical maps with respect to depicting Basel during the cholera outbreak of 1855.

The map was downloaded from the *Geoportal Basel Stadt* and is available as a raster dataset in TIFF format, using the coordinate reference system (CRS) LV95 CH1903+, which is prevalent for Swiss geodata (Bundesamt für Landestopografie swisstopo 2023).

3.1.3 Land register map Basel Stadt 1865-72

The *Grundbuchplan Basler Innerstadt 1865-72* is the land register map for Basel City and draws an additional picture of Basel during the 19th century (Falkner 1872). Its extent is limited to the inner parts of the city. As the map serves as a cadastral map, it is rich in detail. The land register map is depicted in Figure 3.3. The map was created between 1865 and 1872 by R. Falkner (Falkner 1872). It was again downloaded from the *Geoportal Basel Stadt* as a TIFF file in the CRS LV95 CH1903+.

Figure 3.3: Land register map of Basel, created between 1865 - 1872 by Falkner 1872.

3.1.4 Census Data

Bürgerforschung Basel (BBS) With the archaeological excavation of the former hospital cemetery in Basel and its great source of historical medical data on the buried corpses, the citizen science project Bürgerforschung Basel (BBS) emerged and aims at transcribing these data (Hotz and Steinke 2012, Hotz, Zulauf-Semmler, and Fiebig-Ebneter 2016). Besides this medical data, census data has been made available (Hotz, Schumacher, et al. 2015). Worth mentioning is the work of BBS volunteer Verena Fiebig-Ebneter, who transcribed census data from the years 1850 and 1860 of over 70,000 people.

Data source The census data consist of two datasets of the censuses of Basel Stadt for the years 1850 and 1860 (Transkription der Bürgerforschung Basel (BBS) 1850, Transkription der Bürgerforschung Basel (BBS) 1860). These census data have been digitized by the citizen science project Basel Spitalfriedhof BBS and were kindly provided by Gerhard Hotz (Hotz, Schumacher, et al. 2015).

The dataset consists of entries of individuals and provides information on a resident's name, sex, age, civil status, profession, year of birth, and confession. Further, statements about whether the entry concerns a person or property, homeownership, and how many people lived in a household or at one address are noted. In addition to this, the district,

district number, street, and house number or house name are indicated.

Data preparation and processing In this thesis, the attributes sex, age, year of birth, number of people per household, as well as address, district, and district number for each resident were taken into account. The two census datasets 1850 and 1860 were preprocessed in Microsoft Excel.

For visualization purposes and a simpler geolocalisation of individual residents, the census data were aggregated to the district level using the district number. For each year, the median, rather than the mean, of the attributes age, number of people per household, and address were used to counteract outliers. Means of the data attributes' respective outcomes of the years 1850 and 1860 were calculated to approximate the residential population during the cholera outbreak in the year 1855.

To complete these calculations, Python 3 and its package pandas were used (McKinney 2010). The indices that were calculated for each district for the years 1850, 1860, and 1855 (approximated) comprise population size, age, number of people per household, and address, as well as the proportion of people above 60 years and the proportion of females and males. The resulting table was exported as a comma-separated values file (.csv).

The integration into ArcGIS Pro was performed by joining the resulting table on the district level with the district geometries. The join was conducted by the linkage of the district number. The creation of the district geometries will be discussed in the next chapter.

3.1.5 District geometries

Data preparation and processing To assign the census data a geographical extent, the location of the districts that the census data were aggregated to needed to be known. Such a geographical dataset that fits the extent of 1855 Basel districts had not existed until now and was created in this thesis.

The first prototypical approach was to work with contemporary district boundaries of Basel, matching former district names with contemporary district names, assuming that the spatial extent persisted throughout time. Reaching out to Andreas Kettner, the consultant of the land registry of the canton Basel Stadt, he clarified that this approach would not meet the criteria for the geolocalisation of the districts. Subsequently, Andreas Kettner kindly offered to create a more exact shapefile of the district geometries based on cadastre data available to him and explained that these geometries grew historically.

The requirement for this dataset was to correctly assign addresses to their respective districts. In agreement with Andreas Kettner, the shapefile that he subsequently provided was altered to match the Rhein river course mapped in the Situation map 1862 and to simplify certain individual district boundaries with jagged geometries, aiming at preserving the house allocation within a district.

The resulting shapefile was populated with the previously calculated census data table via a join based on corresponding district names in ArcGIS Pro. A map of the districts with their respective names can be seen in 4.1 later in the Results section. The purple square represents the outline of the Situation map from 1862 and serves as a visualization extent throughout this thesis.

Furthermore, cholera case counts for each district were calculated with the use of the spatial join tool in ArcGIS Pro, assigning the number of cholera cases contained in each district. With this cholera count and the population of the respective district's population from the census (approximated to the year 1855), the cholera incidence (amount of cholera cases per 100,000 inhabitants) for each district was calculated. This enables an assessment of the cholera case distribution which is normalized to the background population. Additionally, the number of cholera cases per square kilometer and the population per square kilometer were calculated, and the division into urban and rural Grossbasel and Kleinbasel was assigned.

To grasp the temporal change in incidences for each week throughout the cholera outbreak, the incidences were calculated similarly to the incidences in the paragraph above, using cholera counts for each week. The attribute table was populated with cholera counts and incidences for each district and week, respectively. To be noted is that the background population of the estimated population index for the year 1855 remained the same, whereas no births or deaths, neither from cholera nor other causes, were taken into account.

3.1.6 Well data

For this thesis, a well dataset was developed to take into account the possibility of a center of cholera infection based on contamination of the water source of wells. Given the story of John Snow, who identified the Broad Street Pump, a contaminated water well, as the main distributor of cholera in London in the year 1854, a year before the outbreak in Basel, it is reasonable to adapt his ideas to see if a similar pattern occurred during the cholera outbreak in Basel 1855.

Data sources and preparation The wells dataset for Basel includes data from four data sources. The first approach to reconstructing the 1855 wells was to check whether a geographical dataset on contemporary wells was already available. This was the case, as the official supplier for energy, water, and telecommunication in Basel Stadt *Industrielle Werke Basel* (IWB) hosts a web map service showing all public wells in Basel (Industrielle Werke Basel IWB 2022). The IWB allowed data usage and alteration for this thesis.

The dataset was hence downloaded as a KML file and imported into ArcGIS Pro, where it was converted to shapefile format. The file comprises information on the location, name, and information on the usage of each well, such as whether it serves as a bathing well for recreation or either a drinking or non-drinking water fountain. For this thesis, the well location with its respective name was of interest.

To develop the historical dataset of well locations in mid-19th century Basel, the Situation map from 1862 was consulted. Each of the over 200 IWB wells was manually examined on whether it fits a well within the Situation map. If this was not the case, the well point was deleted from the dataset. The attribute source was set to *IWB* for the remaining wells in this dataset.

The next step was to manually detect the remaining wells which were mapped in the Situation map. For each well, a new geometry was created, assigning the attribute source to *Situation1862*.

Further, wells were mapped the same way by examining the Land register map from 1865-72. The respective source attribute is indicated as *LandReg1865-72* in the attribute table.

In addition to this, a separate map of the *Sodbrunnen* wells in Basel at that time (Staatsarchiv Basel-Stadt 1862), was digitized, whereas all the wells from this map were added. Here the wells' source attribute was assigned as *Sodbrunnen*.

Data processing The resulting well dataset comprised 389 entries. Each well was further assigned a location category, indicating whether the well was situated at a town square, junction, street, green space, or courtyard. In this thesis, only wells that seemed to be publicly accessible, namely those at squares, junctions, and streets, were further included, whereas wells in courtyards or green spaces were not taken into account.

In total, 58 wells met the criteria above. As the wells from the IWB source comprised information on wells, the names were looked up at www.Altbasel.ch (Rebmann 2017) and if available, a link to the respective well description was added under the attribute Altbasel.ch.

Based on this well dataset, Thiessen polygons were created in ArcGIS Pro to approximate the drawing area of each well, assuming that residents seek the nearest public well to access the water supply (Koch and Denike 2009). With the Rhein dividing the city into Grossbasel and Kleinbasel, the river was considered a motion barrier between the two parts of the city. Hence Thiessen polygons were manually adjusted to be restricted to the two respective parts of the city.

Furthermore, the majority (55 of 58) of resulting wells were located in the inner parts of Basel, with only three wells situated in the *Bänne* districts. To avoid outer boundary

Thiessen polygon issues, the boundaries for the Thiessen polygons were clipped to the extent of the inner city districts of Basel without the *Bänne* districts, as seen in e.g. Daffi and Wamyil 2017.

By performing a spatial join, the cholera case counts per Thiessen polygon were calculated to enable visualization of a potential correlation between the well draw area and the respective amount of cholera cases within that area. Cholera counts per Thiessen polygon were normalized to cholera cases per square kilometer.

3.1.7 Geographic characteristics

Water bodies For the river geometries, the contemporary watercourse network (*Gewässernetz*) was downloaded from the *Geoportal Basel Stadt* in shapefile format (Kanton Basel-Stadt 2019). River course geometries of the Birsig, Rümelinbach and St. Alban Teich were adjusted to match the Situation map from 1862. The smaller waterbodies of Kleinbasel which can be seen in the Situation map 1862 were added to the dataset manually by creating new objects in ArcGIS Pro.

As the river courses are available as line geometries, an additional layer was created to show the width of the Rhein river. Its extent is again matched with the Situation map 1862. The resulting datasets can be seen in Figure 3.4.

Digital Terrain Model To get an overview of the topography of the research area, a digital terrain model (DTM) was used. The DTM is publicly available on www.swisstopo.ch, the Federal Office of Topography of Switzerland (Bundesamt für Landestopografie swisstopo 2022). The digital terrain model, officially named *swissALTI3D*, can be downloaded in form of individual tiles (GeoTIFF) with a size of one square kilometer. These tiles consist of raster data available in 0.5 m and 2 m spatial resolution. In this thesis, the coarser resolution of 2 m was used to keep data storage sizes low as its resolution is sufficient for its purpose to show the topography of Basel. To minimize storage size, nine tiles covered most of the Situation map's extent, while the outer areas not covered by these nine tiles were omitted.

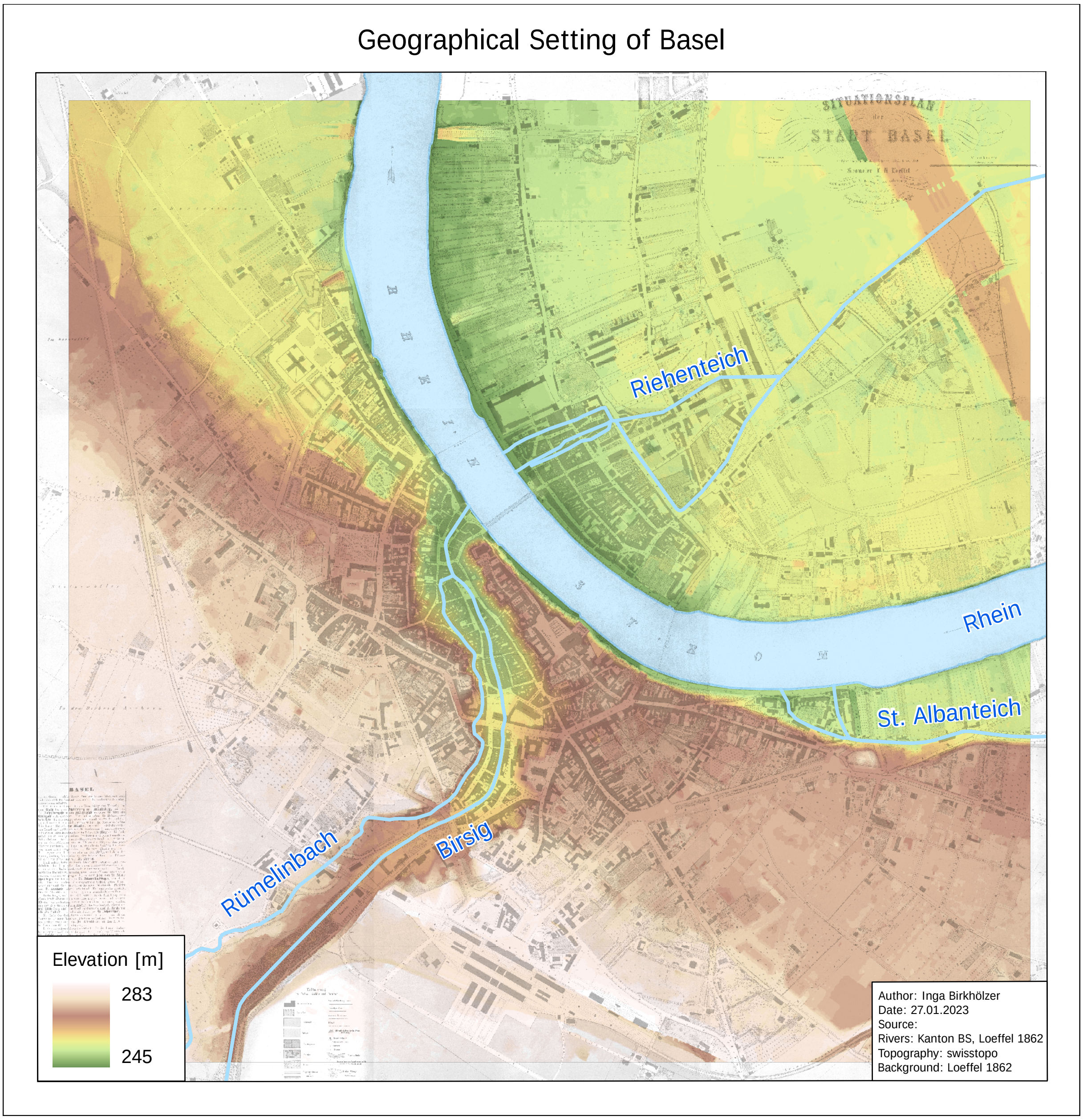


Figure 3.4: Elevation and river courses in Basel.

3.1.8 Street geometries

Similarly to the river data, the basis of the street geometries was the contemporary street network. For this, the street name dataset (*Strassennamen*) was downloaded in shapefile format (Kanton Basel-Stadt 2022). The spatial extent was again matched with the Situation map 1862. Each street was altered to match the geometries in the Situation map.

Even though the contemporary street network comprises information on street names, these do not match with the street names of 19th century Basel. For this thesis, information on street names was not adjusted to the Situation map and the dataset was not used for further visualizations. The dataset on the road network therefore only serves as an illustration. In order to use this dataset in the future, especially geometries at larger squares should be ameliorated to match the intended purpose of the dataset, i.e. whether geometries should proceed near buildings or through the middle of a square.

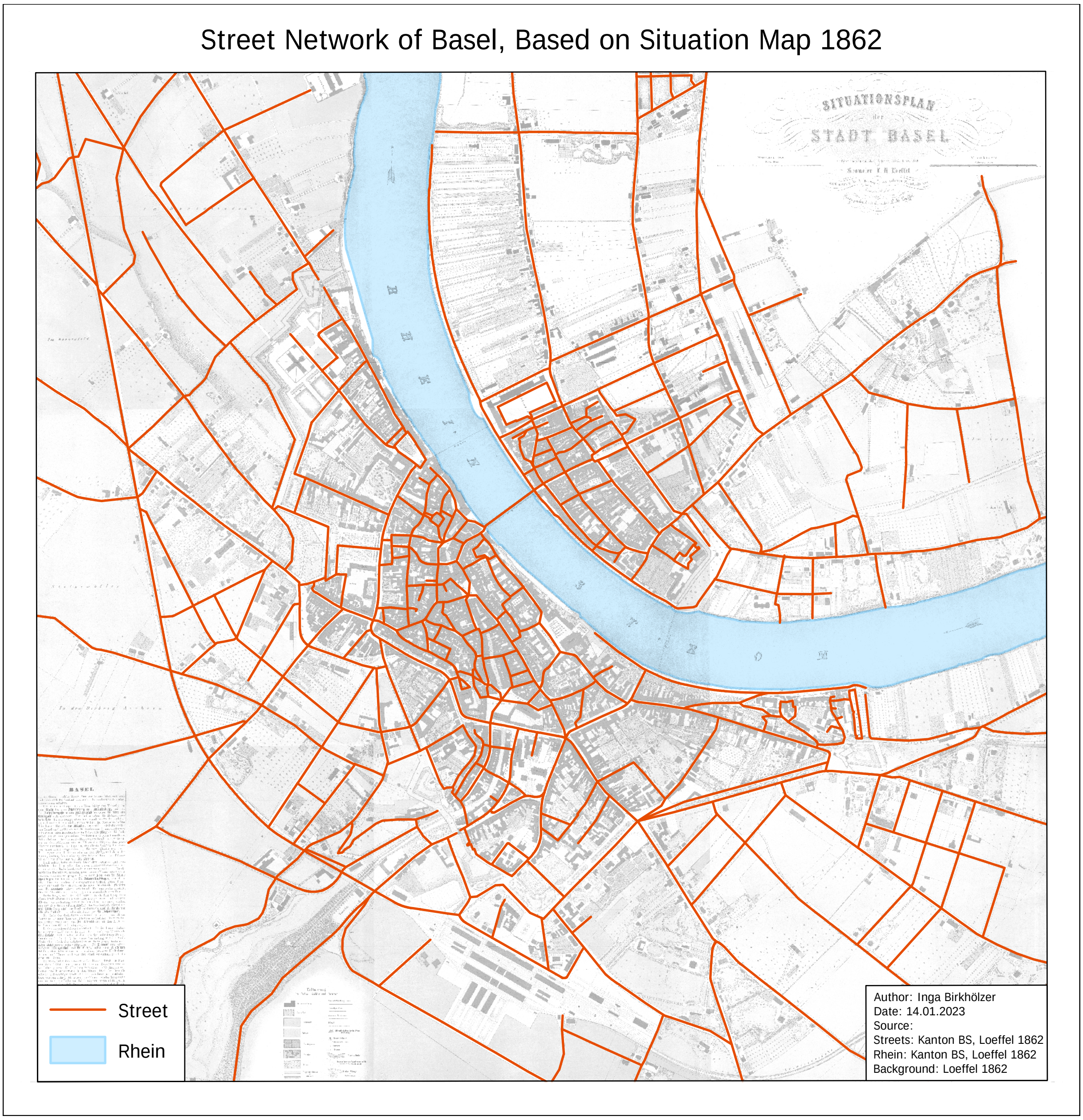


Figure 3.5: Street network of Basel, based on the Situation map by Loeffel and Falkner 1862.

3.2 Data management

The main software used for this thesis is ArcGIS Pro (version 3.0.x). It was used for data collection and storage, alteration and exploration, and to create maps and graphs.

This thesis's map designs aim to meet the cartographic standards of Slocum et al. 2013. Map elements and layers were positioned based on their relevance, drawing attention to the central theme of the respective map, according to Slocum et al. 2013, p. 216.

3.3 Choices regarding geovisualization

Map layout The horizontal map size was determined by the text width of the thesis file (160 mm), and the vertical height of each map was altered to fit the content and map elements. Maps were exported from ArcGIS to PDF files, allowing vector data to be depicted clearly in the final thesis file.

A frame line was drawn around the maps to make a clear distinction between the map content and the written text of the thesis. To emphasize the maps' extent, a neat line was used as advised in Slocum et al. 2013, p. 217.

Map extent The spatial extent of most of the maps shown in this thesis shares the extent of the Situation map (Loeffel and Falkner 1862). This map covers roughly ten square kilometers. Due to its square shape, the map layout is suitable for presenting the map product both in high portrait formats, as seen in this thesis, and in the horizontal format used to deliver the thesis results to an audience. With the thesis' thematic emphasis on the inner parts of Basel, the rural spaces in the maps' corners were filled with elements such as legends or information on data sources.

The Situation map extent was used as an outline to digitize geodata such as wells and rivers.

The extent of Basel's districts was used to show the respective districts' areas referred to in the census data from 1850 and 1860. In other maps, this extent was avoided due to the large size of the four *Bänne* districts and the emphasis on the inner parts of the city.

For orientation purposes, the Rhein river geometry was added to most map layouts, emphasizing the natural divide between Grossbasel and Kleinbasel. An altered version of the Situation map, only showing the red band of the data as a greyscale map, was included in the form of a transparent background in map themes that did not include data on the district level. This measure was taken to enable spatial orientation within the map extent, such as the location of buildings or streets and street names and the extent of the city in general.

Choice of colors and symbols Color, with its components of hue, lightness, and saturation, is an important visual variable in the creation of maps (Slocum et al. 2013, p. 94). Hence, attention was paid to how the different topics, which were looked at in this thesis, should be depicted color-wise, both in terms of visualizing data qualitatively and quantitatively (Slocum et al. 2013, p. 94). For this, cholera-related outcomes were visualized in color hues different to data unrelated to cholera abundance, e.g., population data.

The cholera point data in Figures 4.5 and 4.14 are black with a white outline. Black was mainly used because of its great contrast to the underlying layers, further emphasizing the intellectual and visual hierarchy of the cholera case points, which is the most critical layer in respective maps (Slocum et al. 2013, p. 243). The white outline was chosen to distinguish individual points in case of overlap. However, with the Situation map extent and the varying point size, overlap occurred in the highly affected parts of the city.

On an aggregated level, cholera counts per district are represented by proportional circles in Figure 4.8. For circle sizes, a Flannery correction was applied to overemphasize large circles, as indicated in Slocum et al. 2013, p. 367. Here, circle colors were depicted in a light shade of lavender, lining up the visual hierarchy with the incidences, as both pieces of information serve the map's content. The incidences are displayed on the district level, representing the available area subdivision for the census data, by means of which cholera case numbers were normalized. For this, a choropleth map was chosen, using the sequential multi-hued color scheme "Red-Purple" developed by Cynthia Brewer (C. Brewer et al. 2002). This color theme was used based on its interpretability through the combination of color hue and value, while also taking into account different varieties of color blindness. These characteristics were checked on the website colorbrewer2.org (C. Brewer et al. 2002). The subject of including color-vision impairments in map making has been researched by Olson and C. A. Brewer (1997).

All maps using classified data were symbolized using the Natural Breaks (Jenks) method. The Natural Breaks method aims to minimize the differences within a class while maximizing the difference between classes (Slocum et al. 2013, p. 72). This classification method has its flaws, especially as the legend may not be easily understandable (Slocum et al. 2013, p. 76). Yet, the method is used in this thesis as the underlying pattern of the data is visible, especially as certain areas comprised comparingly very high data values.

The Kernel Density Estimation (KDE) was computed in ArcGIS Pro using the following input variables: The output cell size was set to 16 meters with a kernel search radius of 30 meters, whereas the output cell values represent the estimated case density. The geometry of the Rhein river was included as an input barrier feature to avoid density estimations extending into the river and to represent the Rhein as a motion barrier in the city. In the KDE visualization, the "Red-Purple" color scheme was used again to match the topic of cholera distribution. The color of the lowest density class was set to invisible to put emphasis on the remaining higher classes.

For the Thiessen polygons around the wells in Figure 4.13, the same "Red-Purple" color scheme (C. Brewer et al. 2002) was used to emphasize the thematic connection between the two maps, which is the cholera rate, either per background population in the form of an incidence, or per square kilometer, indicating the case density.

A blue tear, symbolizing water, represents the well location. For this, a darker shade of blue was used to differentiate between wells and water bodies.

To emphasize the location of the wells and to make a statement about street names, the Situation map was chosen as a background map, similar to Figure 4.5. To avoid interpretation difficulties with layering the colored Thiessen polygons over the colored Situation map, band symbolization was altered to only depict the red band, accentuating buildings, which were depicted in red by the author Loeffel (Loeffel and Falkner 1862). This gives the Situation map more contrast, especially for people with deuteranopia (red-green blindness), as the original situation map comes mostly in red and green shades. On the other hand, by being black and white, the background map is not drawing too much attention from the main content of the map, which is the depiction of wells and their respective Thiessen polygons.

The topography data in the form of a digital terrain model was depicted by a color ramp representing the elevation gradient for an intuitive understanding of the elevation over the research area. Cholera cases were displayed by black circles, as described previously. The color ramp of the elevation data was checked for color-vision impairments using the respective tool in ArcGIS Pro. The elevation values were stretched over the color ramp using a percent clip. The aim was to make drastic changes in elevation, i.e., steep slopes, visible. The use of a shaded relief was omitted as this map aims to give an overview of the relative elevations throughout the city and due to otherwise visual overload with the simultaneous display of the Situation map.

Similar to the map of the wells in 4.13, the transparent greyscale depiction of the Situation map 1862 was used as a background for orientation purposes. This is useful to get an understanding of the elevation compound of the streets throughout the city.

Bivariate maps can be used to show two variables simultaneously in the form of one map (Stevens 2015). Like univariate maps, bivariate maps can visualize binary, qualitative, diverging, or sequential data (C. Brewer n.d.(a)). The data that were used for the bivariate maps (cholera incidence, number of people per household and address), were visualized in a sequential color scheme of sequential blues and pinks. These two color dimensions are layered, creating distinctive colors for the qualitative assessment of the input data ranging from low to high (Stevens 2015). This color scheme is available as an option in

ArcGIS Pro and was created by Cynthia Brewer (C. Brewer n.d.(b)). This segmentation into low, midrange and high values leaves out a clear distinction between the respective values, however, it is rather easy to interpret. More precise values of the cholera incidence can be extracted from the map in Figure 4.8 and numbers on the household and addresses are noted in the accompanying text.

3.4 Data publication

All geodata created and/or used in this thesis will be collected and saved on a server at the Department of Geography of the University of Zürich. The data will be equipped with appropriate metadata. To access these data, please contact Dr. Tumasch Reichenbacher (Contact: tumasch.reichenbacher@geo.uzh.ch), group leader of Geographic Information Visualization and Analysis at the Department of Geography, University of Zurich. The same data and documentation files will also be published via publications and other channels of the research group "Anthropometry and Historical Epidemiology" at the Institute of Evolutionary Medicine, University of Zurich (Contact: kaspar.staub@iem.uzh.ch).

4 Results

4.1 Population distribution of Basel 1855

To get a broad overview over mid-19th century Basel, the city's extent, resulting from the creation of the district borders based on the census' district classification, can be seen in Figure 4.1. The map gives an insight into the districts and their respective names, as well as whether the districts are situated in the inner city (urban) or outside the inner city (rural) in the *Bänne* districts.

Grossbasel exists of six inner city districts (*Stadt*, *St. Johann*, *Spahlen*, *Steinen*, *Aeschen*, and *St. Alban*, as well as the two outer city districts *Unterer Bann* and *Oberer Bann*. Kleinbasel is divided into the two inner city districts *Bläsi-Quartier* and *Riehen-Quartier*, as well as the two rural districts *Bläsi Bann* and *Riehen Bann*. Grossbasel and Kleinbasel are separated by the river Rhein, which is cut to the extent of the Situation map, flowing from the east to the north.

For a general overview of the population distribution of Basel in 1855, the census data from 1850 and 1860 were aggregated to approximate the year 1855. The resulting population size and density in the form of population per square kilometer are depicted in 4.2.

The urban districts of Grossbasel and Kleinbasel include similar population sizes, ranging from 2780.5 inhabitants in the smallest district *Stadt* to 4178.5 inhabitants in *Spahlen*. The population density is highest in the *Stadt* district, followed by the *Bläsi-Quartier* and *Spahlen* districts. The rural *Bänne* districts are comprised of between 1087 people in the *Bläsi Bann* district to 1544.5 inhabitants in the *Unterer Bann*. In relation to district size, the population distribution shows a similar pattern, with high population densities in the urban areas of the city and low population densities in the outer *Bänne* districts. Population per district size is highest in the *Stadt*, followed by the *Bläsi-Quartier* and the *Spahlen* districts.

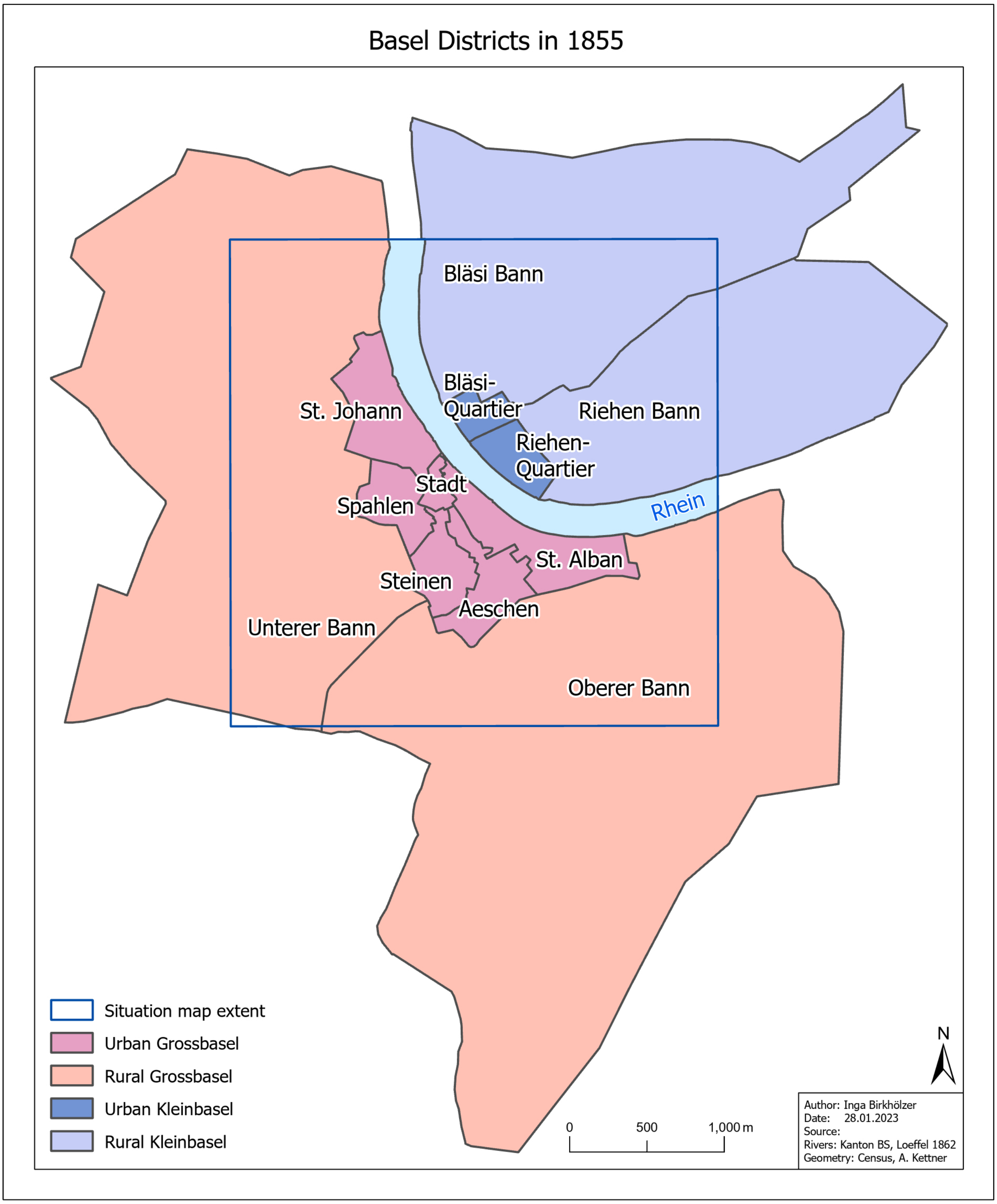


Figure 4.1: Overview of the districts in Basel, 1855.

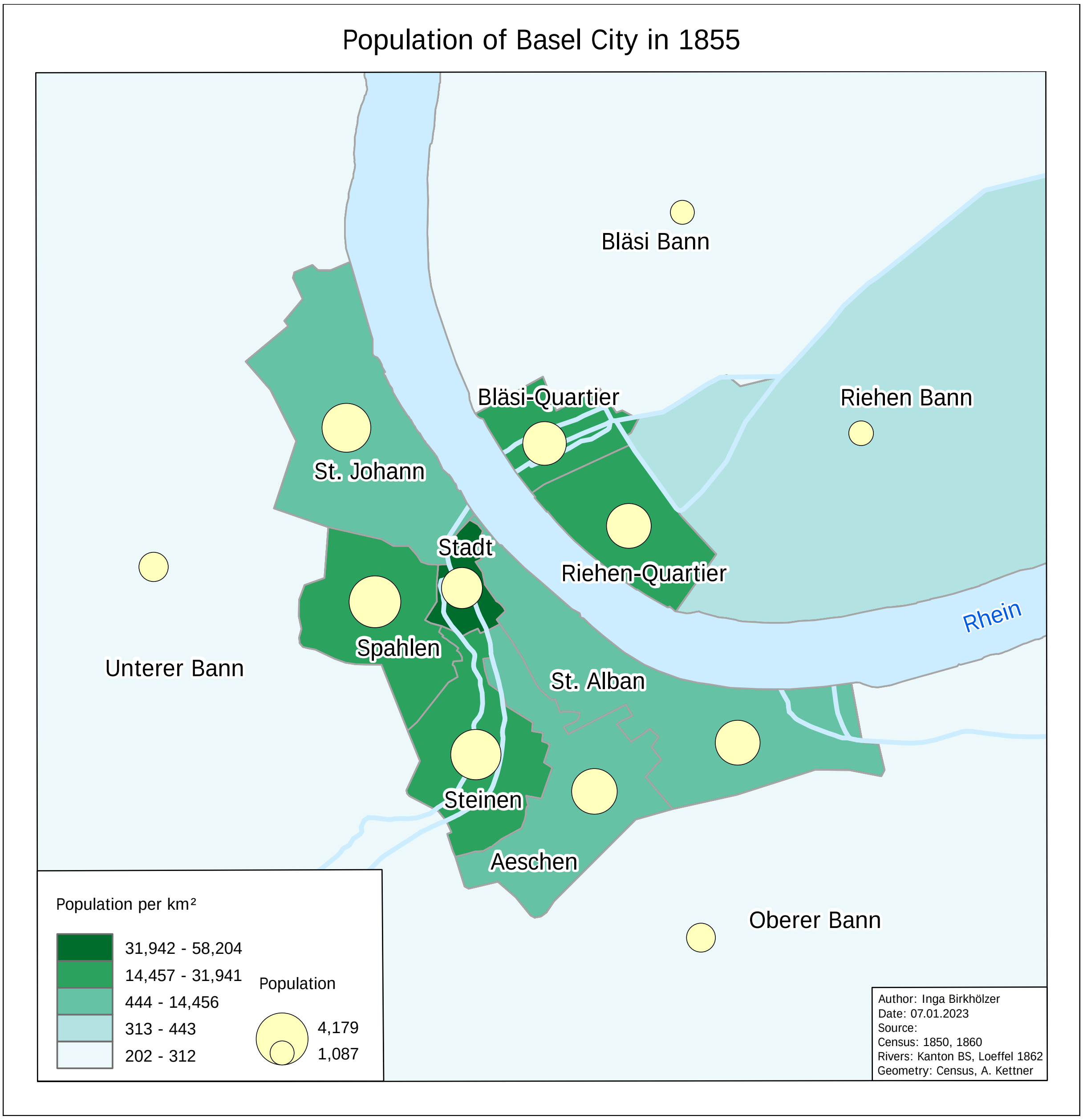


Figure 4.2: Approximated population distribution and density on district level based on the census data from 1850 and 1860.

4.2 Temporal distribution of the cholera outbreak

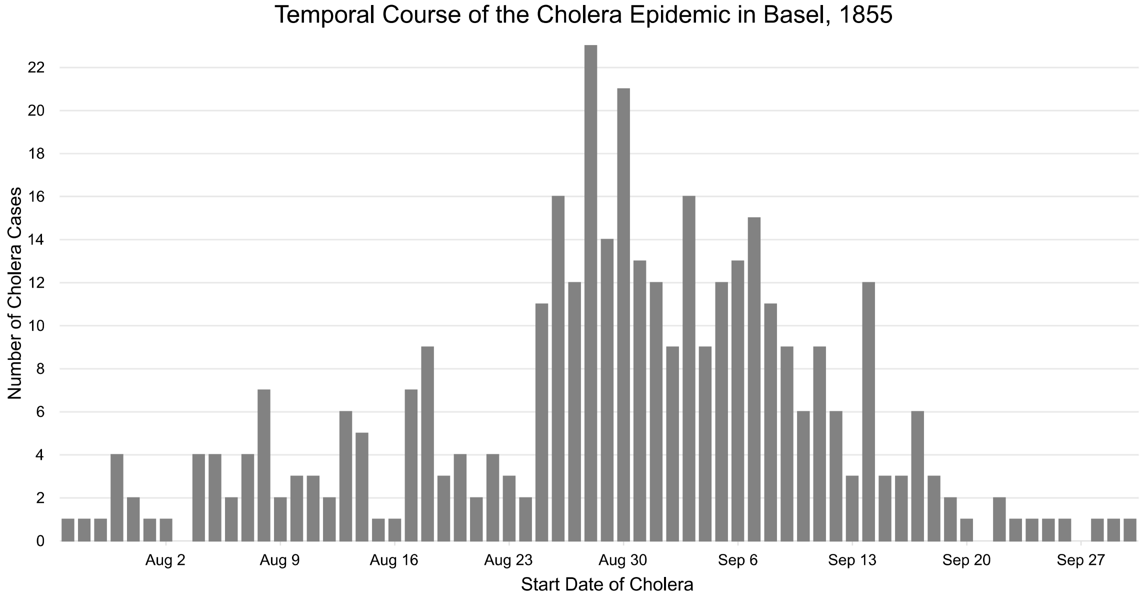


Figure 4.3: Amount of new cholera cases per day.

The dataset which resulted from the digitization and georeferencing of the cholera cases comprises a total of 382 cholera infections.

The first cholera case in Basel 1855 was reported on July 27. A histogram of the number of cholera cases per day can be seen in Figure 4.3. The outbreak started with few cases per day and for the first four weeks, case numbers ranged from zero to nine cases a day. Case numbers increased rapidly in week 5, reaching a maximum of 23 cases on August 28, 1855. Case numbers per day decreased more slowly than they had increased, and case numbers stayed high for three weeks. After the middle of September, only a few cases per day occurred, and the last cholera case of this outbreak was reported on September 30, 1855.

Figure 4.4 shows the distribution of the cholera cases and their respective outcome in death or recovery. The dates indicate the start of the disease and not the date of death to match the graph in Figure 4.3. In total, 197 people died of the 382 cholera cases counted in this thesis. Despite the overall equilibrium between cholera resulting in death or recovery, the outcomes differ from day to day.

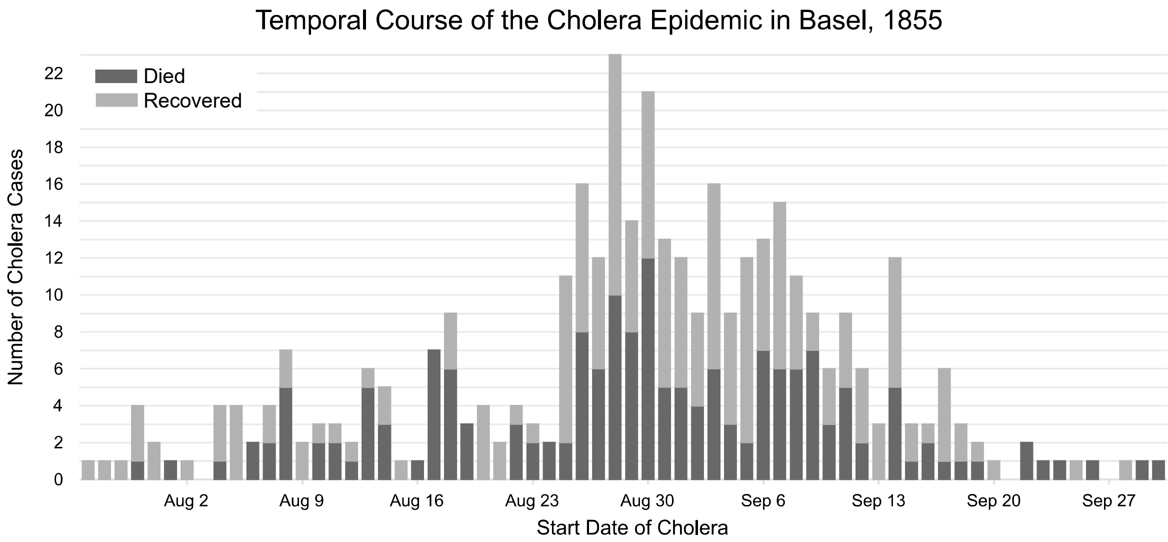


Figure 4.4: Amount of new cholera cases per day by death or recovery.

4.3 Spatial distribution of cholera cases

Individual cholera case distribution The spatial distribution of the cholera cases resulting from the digitization and georeferencing of the historic cholera records can be seen in Figure 4.5. Of the 382 cases included in this thesis, 376 fall into the extent of the Situation map from 1862, and six cases exceed this extent. It can be seen that cases occurred mainly in the inner parts of the city where houses are mapped in the Situation map of 1862. In the more rural appearing areas outside the city, cholera occurred more scarcely, likely due to lower population size and density, as can be seen in Figure 4.2.

Regarding the visualization of the cholera cases, Figure 4.5 shows individual case points. To visualize multiple cases located at the same address, point size was varied according to the respective case count.

A Kernel Density Estimation (KDE) (see Figure 4.6) was done to simplify the cholera case pattern. The map reveals the cholera hotspots of Basel during the outbreak of 1855, which lie mostly in urban Kleinbasel and in urban Grossbasel, as well as in the *Oberer Bann* district. In Kleinbasel, cholera case hotspots cover almost the whole extent of its districts *Riehen-Quartier* and *Bläsi-Quartier*, with the highest estimated density in the area of the *Rheingasse*. In Grossbasel, cholera cases are not restricted by district borders. The hotspots occur in the heart of Grossbasel, covering the whole *Stadt* district and adjacent parts of the neighboring Grossbasel districts. Areas near the outer borders of these districts are not affected as heavily, with respective hotspots lying within the borders of urban Grossbasel. In the rural parts of the city, only a few hotspots were located with the Kernel Density Estimation. However, a noticeable, circular hotspot occurred in the *Oberer Bann* district.

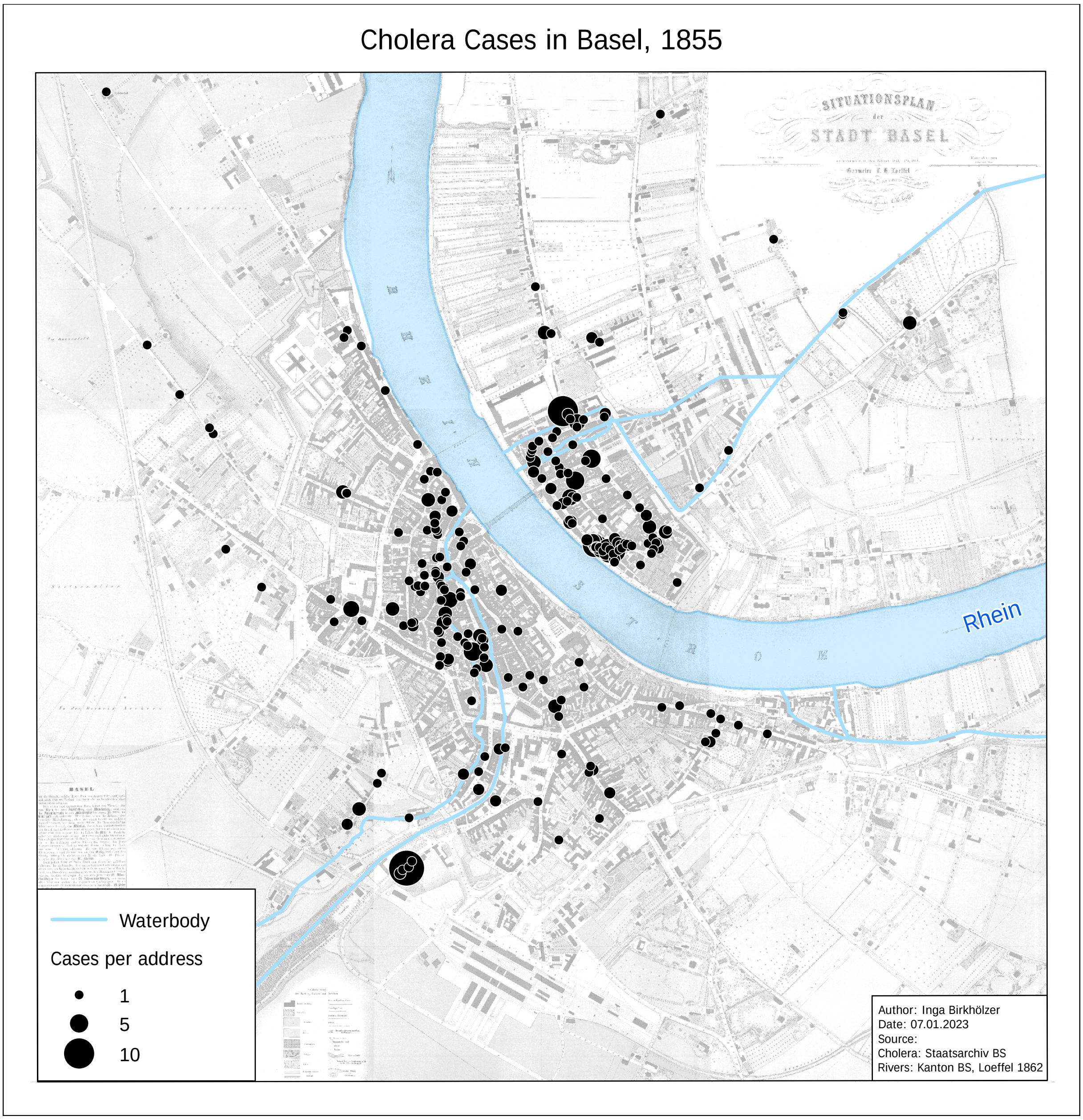


Figure 4.5: Point distribution of cholera cases in Basel, 1855.

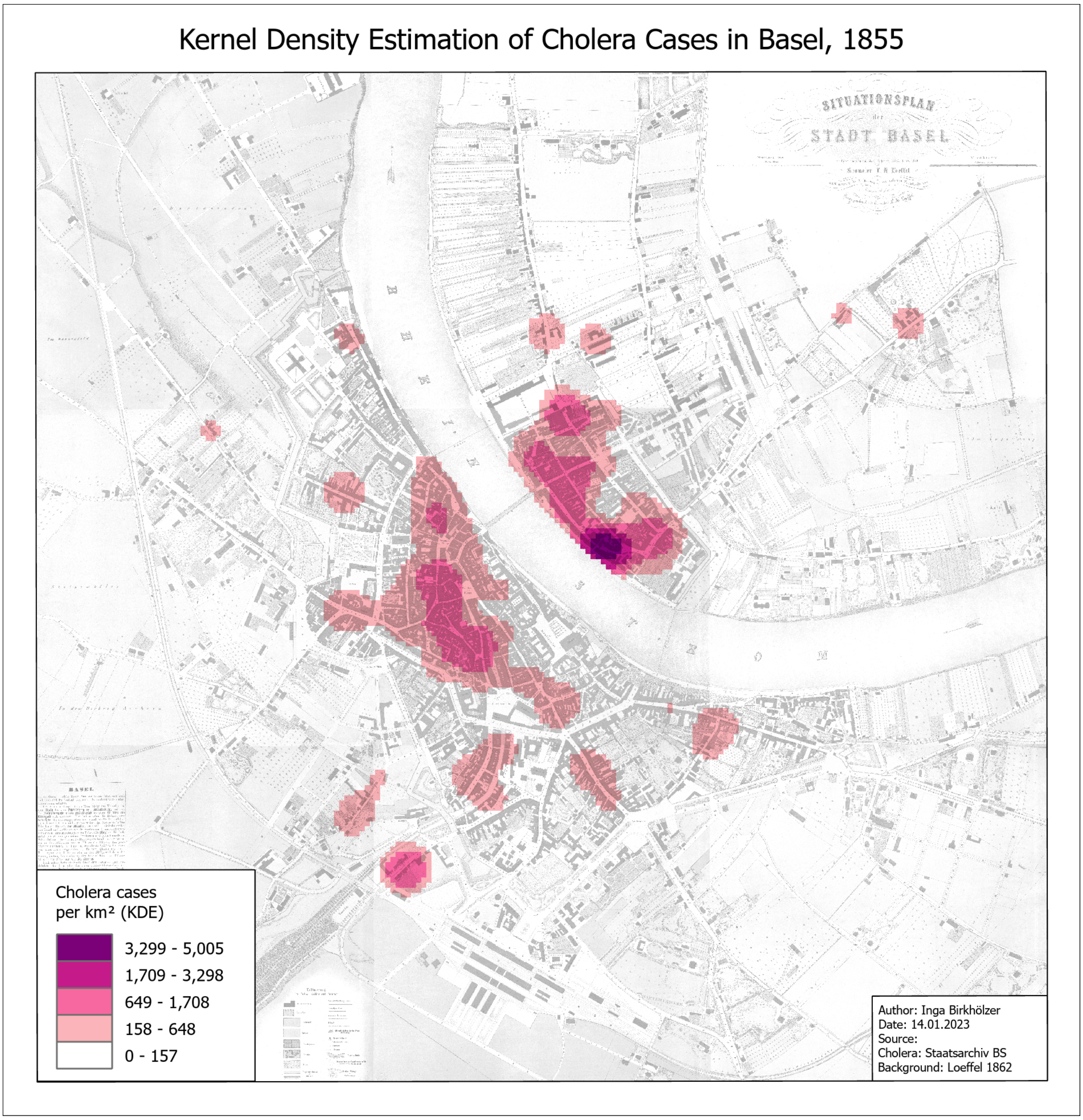


Figure 4.6: Kernel Density Estimation showing spatial clustering of cholera cases in Basel, 1855.

Distribution of cholera on district level

Cases numbers Aggregating the cholera cases to the district level resulted in the differently sized circles in Figure 4.8 and bars in Figure 4.7. Of the 382 cholera cases, 115 cases occurred in the *Riehen-Quartier*, followed by 49 cases in the adjacent *Bläsi-Quartier*. Case numbers within the urban Grossbasel districts are similar, except for comparatively few cholera cases in *St. Alban* district, where fewer cases occurred than in the rural *Oberer Bann*.

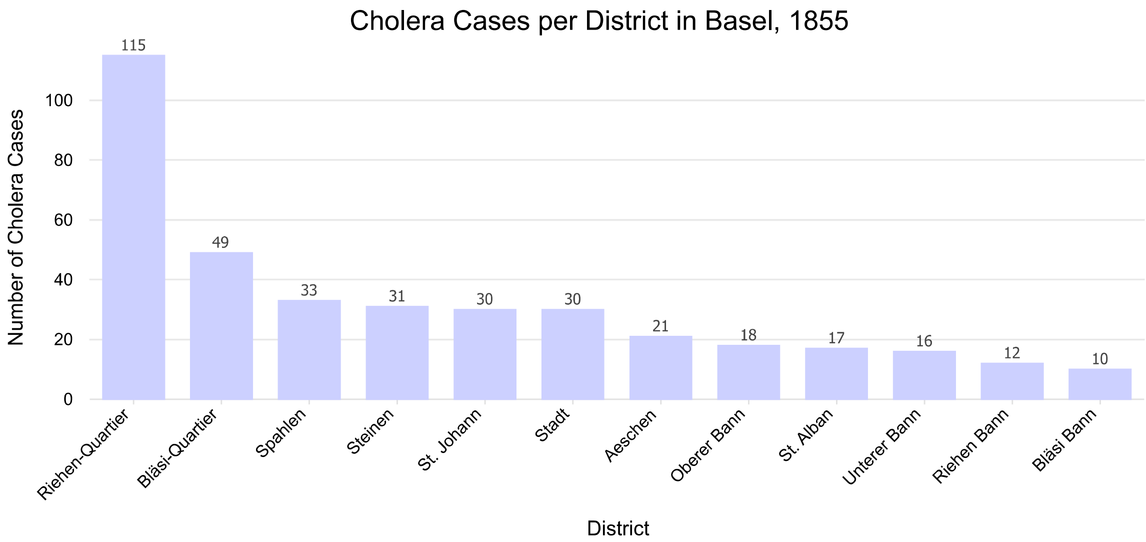


Figure 4.7: Number of cholera cases per district in Basel, 1855.

Incidence The overall incidence of cholera cases per 100,000 inhabitants during the outbreak in Basel in 1855 is 1160.5. This number is based on the 382 cholera cases residing in Basel at that time, and the approximated population of 32,916 inhabitants in Basel in 1855. In Figure 4.8, cholera incidences for each district are depicted. The highest incidences can be found in *Riehen-Quartier* (3554) in Kleinbasel on the right bank of the Rhein, whereas the adjacent district *Bläsi-Quartier* (1584) has the second-highest incidences, although much lower than in *Riehen-Quartier*. In the inner city of Grossbasel, the *Stadt* district (1079) was more affected than the surrounding districts *St. Johann* (795), *Spahlen* (790), *Steinen* (780) showing similar incidences. Low incidences occur in *St. Alban* (523) and *Aeschen* (627) districts.

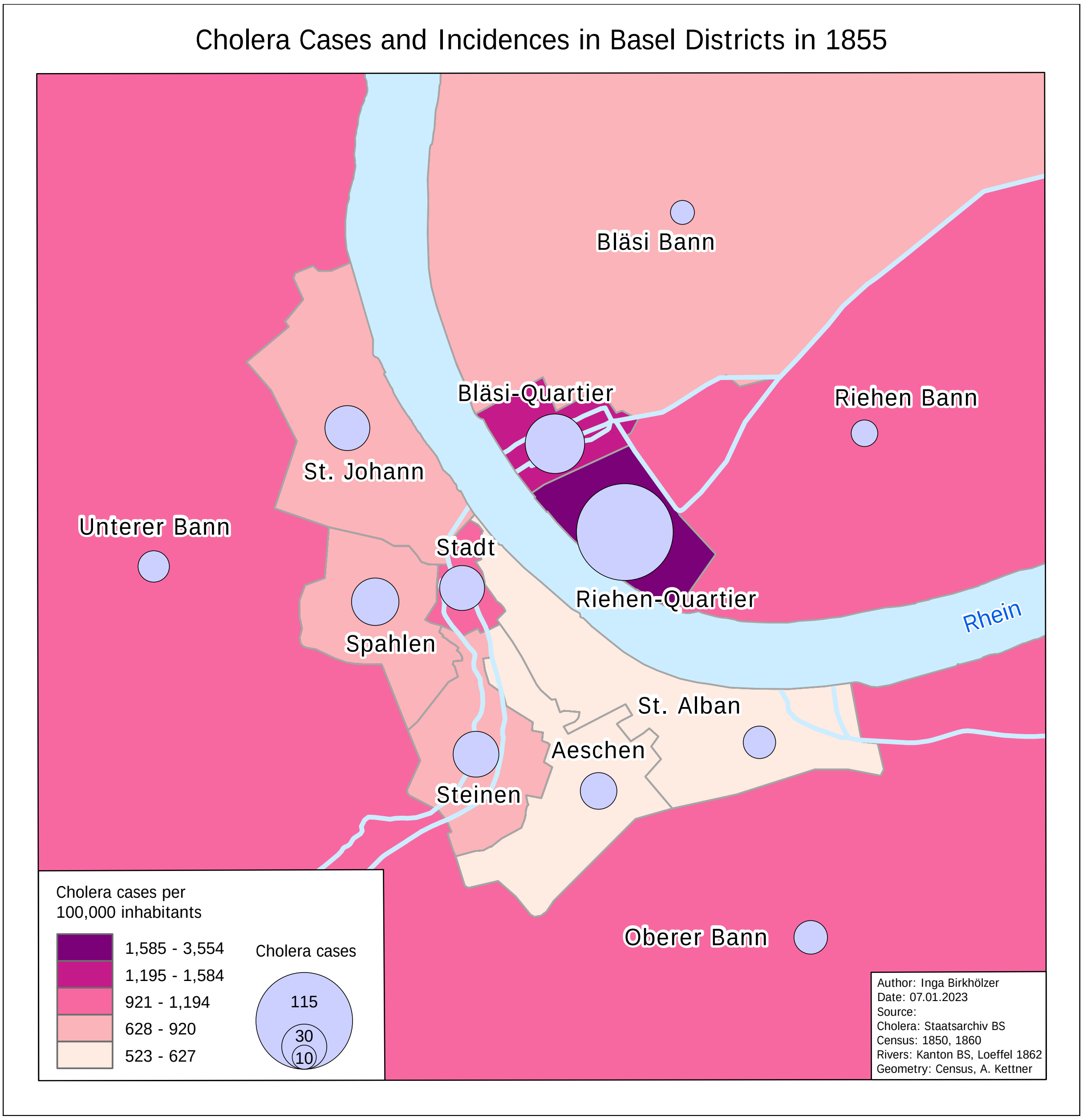


Figure 4.8: Cholera cases and incidences per district in Basel, 1855.

Cholera Density To address the number of cholera cases in comparison to the district size, cholera cases per square kilometer were calculated for each district and can be seen in Figure 4.9. Similar to the incidence map in Figure 4.8, the cholera case density is the highest in the Riehen-Quartier district, followed by Bläsi-Quartier district. Looking at Grossbasel, the highest cholera densities can be found in the Stadt district, with lower densities in the surrounding districts. The lowest densities can be found in the Bänne outside the city, which stands in contrast to the incidence pattern in Figure 4.8, where case numbers in relation to the background population were higher than in the Grossbasel inner city districts, apart from the *Stadt* district.

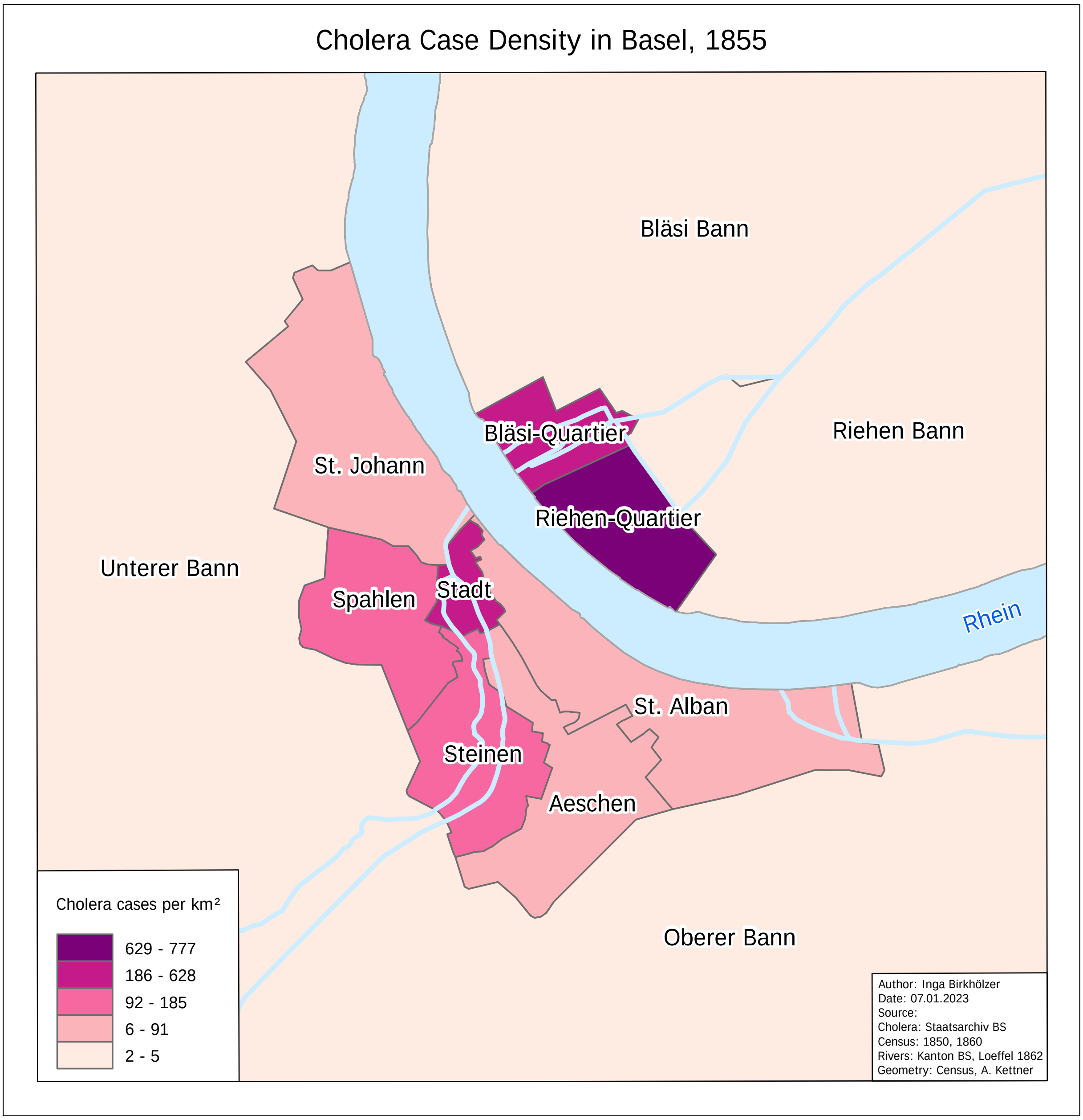


Figure 4.9: Density of cholera cases. Amount of cholera cases per square kilometer.

In Grossbasel and the four *Bänne*, the cholera case density in Figure 4.9 shows a more similar pattern to the overall population density per district, as seen in Figure 4.2. However, population densities in the Kleinbasel *Riehen-Quartier* and *Bläsi-Quartier* do not stand out, whereas the cholera case densities are highest in the *Riehen-Quartier* district with 777 cases per square kilometer. The *Stadt* district with 628 cases per km^2 comprises a higher case density than *Bläsi-Quartier* with 506 cases per km^2.

Deviation of cholera cases on district level Comparing the cholera case numbers on district level, 382 cholera cases were georeferenced and included in this thesis. These numbers align with De Wette's report, which originally counted 399 cases, of which 382 cases fell into the extent of the city of Basel (1856). Despite this congruence in the number of total cholera cases in Basel, numbers deviate on the district level, e.g. in Kleinbasel, where De Wette (Ludwig De Wette 1856) counted 109 cholera cases in the *Riehen-Quartier* and 59 in the *Bläsi-Quartier*. In this thesis, 115 cases in the *Riehen-Quartier* and 49 in the *Bläsi-Quartier* were found. This deviation of +6 and -10 cases, may originate from the different understanding of the district extents, both at the time of De Wette and today with the creation of the district geometries. Although it is assumed that De Wette used the same source (Staatsarchiv Basel-Stadt 1855) for his evaluation of the 1855 cholera epidemic in Basel, the numbers do not fully match. In Kleinbasel, it is possible that the border between the *Riehen-Quartier* and *Bläsi-Quartier* districts could be unprecise. Further, in this thesis, the rural *Riehen Bann* and *Bläsi-Bann* showed deviations from De Wette's number of +2 and +3, respectively. Hence, it is likely that the borders between urban and rural Kleinbasel were not aligned, as urban Kleinbasel showed a deficit of -4 in this thesis, whereas rural Kleinbasel counted a surplus compared to De Wette's numbers. Over the whole extent of Kleinbasel, one cholera case more was counted, with one case less in urban Grossbasel. In urban Grossbasel, the districts *Steinen* (-5), *St. Johann* (-1), and *Stadt* (-2) fewer cases were counted than in De Wette's report, whilst more cases were assigned to *Aeschen* (+1) and *St. Alban* (+6).

Synthesis of the epidemic's spatial distribution The spatial distribution of the cholera cases in Basel in 1855 is depicted in Figures 4.5, 4.6, 4.8, and 4.9 in form of a point map, a Kernel Density Estimation, an incidence map on a district level with proportional circles representing the absolute count of cholera cases per district and a cholera density map showing cases per km^2.

Each of these maps contributes to showing the cholera distribution in Basel in its own way by using different visualization methods. The synthesis of these maps with their strengths and weaknesses reveals the pattern of the cholera outbreak in Basel in 1855.

The point map in Figure 4.5 shows the actual location of cholera cases in Basel, however, the most affected areas suffer from overlap, e.g. in the *Riehen-Quartier*. By showing the

Kernel Density Estimation in Figure 4.6, attention is drawn to the highly affected areas of the city. The numbers of the KDE can be compared with the cholera density map in 4.9. Due to the aggregation to bigger areas, the number of cases per square kilometer is lower on the district level than on the calculated pixel level, where cases nearby get taken into account. This phenomenon is also visible in the urban districts of Grossbasel. Here, although the highest densities are found in the *Stadt*, the KDE pattern is not restricted to district borders and spreads to the districts *Spahlen* and *Steinen*, which is also represented in the density map. However, large case densities occur only in a small area compared to the *Spahlen* and *Steinen* district sizes. Hence, the densities within a district are not uniform, which is the limitation of visualizing the cholera densities using a choropleth map. Choropleth maps are the most useful if the values they represent are uniform within their borders (Slocum et al. 2013), yet this was the only way to integrate the background population in this thesis with the available data.

With the integration of the census data on the district level, the population distribution in Basel in 1855 could be approximated (see Figure 4.2). This pattern stands in relation to the Situation map of 1862 (Figure 2.3), showing urban infrastructure in the city and broad, rural green spaces outside the city, indicating a similar pattern of populated areas.

Cholera cases of each district could be compared with each other after setting them into relation to the population at risk, resulting in the incidence map in Figure 4.8. The pattern is generally similar to the KDE and cholera density maps, yet the *Bänne* district incidences are high compared to the actual numbers of cholera cases. The few outbreaks that occurred in these areas carried more weight due to the small population sizes.

Due to the rather uniform population densities within urban Grossbasel (see Figure 4.2), the pattern of the Kernel Density Estimation demonstrates the pattern of the cholera outbreak the best. The areas that were affected the most severely were the *Riehen-Quartier* in Kleinbasel, especially around the *Rheingasse* street. In Grossbasel, the inner city was affected the most, with the cholera hotspots spreading along the Birsig river, rather than being limited to district borders. Further smaller outbreaks occurred sporadically in Grossbasel.

4.4 Spatio-temporal distribution of cholera cases

Looking at how the spatial pattern varies throughout the course of the epidemic can give an insight into how cholera spread through Basel. For this, a series of maps showing cholera case points for each of the ten cholera weeks was created and can be seen in Figure 4.11. Additionally, daily case counts for the inner city, partitioned into urban Grossbasel and urban Kleinbasel districts, are depicted in Figure 4.10.

Comparing the temporal progress of the outbreak in urban Grossbasel ($n = 162$) and Kleinbasel ($n = 164$), the patterns differ from each other, even though case numbers are

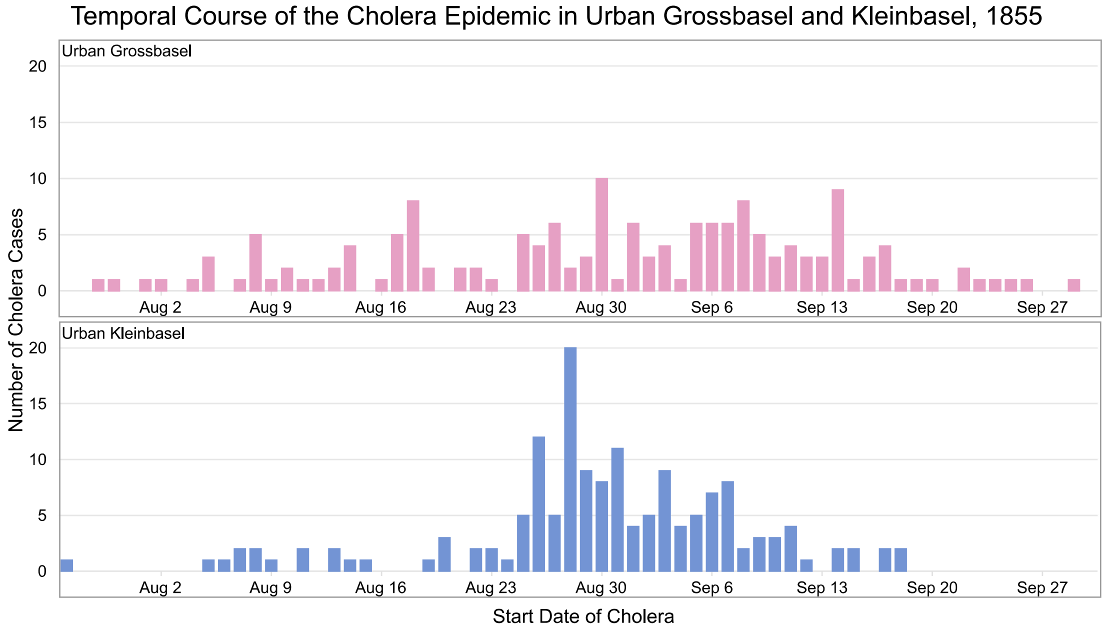


Figure 4.10: Cholera case numbers per day in urban Grossbasel and Kleinbasel, 1855.

similar and the outbreaks took place simultaneously. In Grossbasel, daily cholera case numbers occur during the entire course of the outbreak with rather similar numbers. In comparison, after a few sporadic cases in the first weeks, the Kleinbasel outbreak takes off around August 24, 1855, as could already be seen in the general temporal course of the outbreak in Figure 4.3, although without information about where these cases occurred. During this week, case numbers increased exponentially, peaking on August 28 with 20 cases in Kleinbasel. Meanwhile, in Grossbasel, only two cases were counted on this day.

The *Rheingasse* street in the *Riehen-Quartier* district was affected the most, with 61 cases. Out of these, 42 cases occurred in the seven days between August 25 to August 31, 1855. After this week, cases in *Rheingasse* dropped drastically to one to two cases per day by September 1. However, not only *Rheingasse* street was affected during these weeks, for example the adjacent houses at *Utengasse* and *Lindenberg* street, as well as other parts of Kleinbasel. The four weeks at the peak of the cholera epidemic in the inner city parts of Basel can be seen in Figure 4.12. This distribution again shows that the *Rheingasse* was in fact predominantly a disease hotspot during weeks 5 and 6.

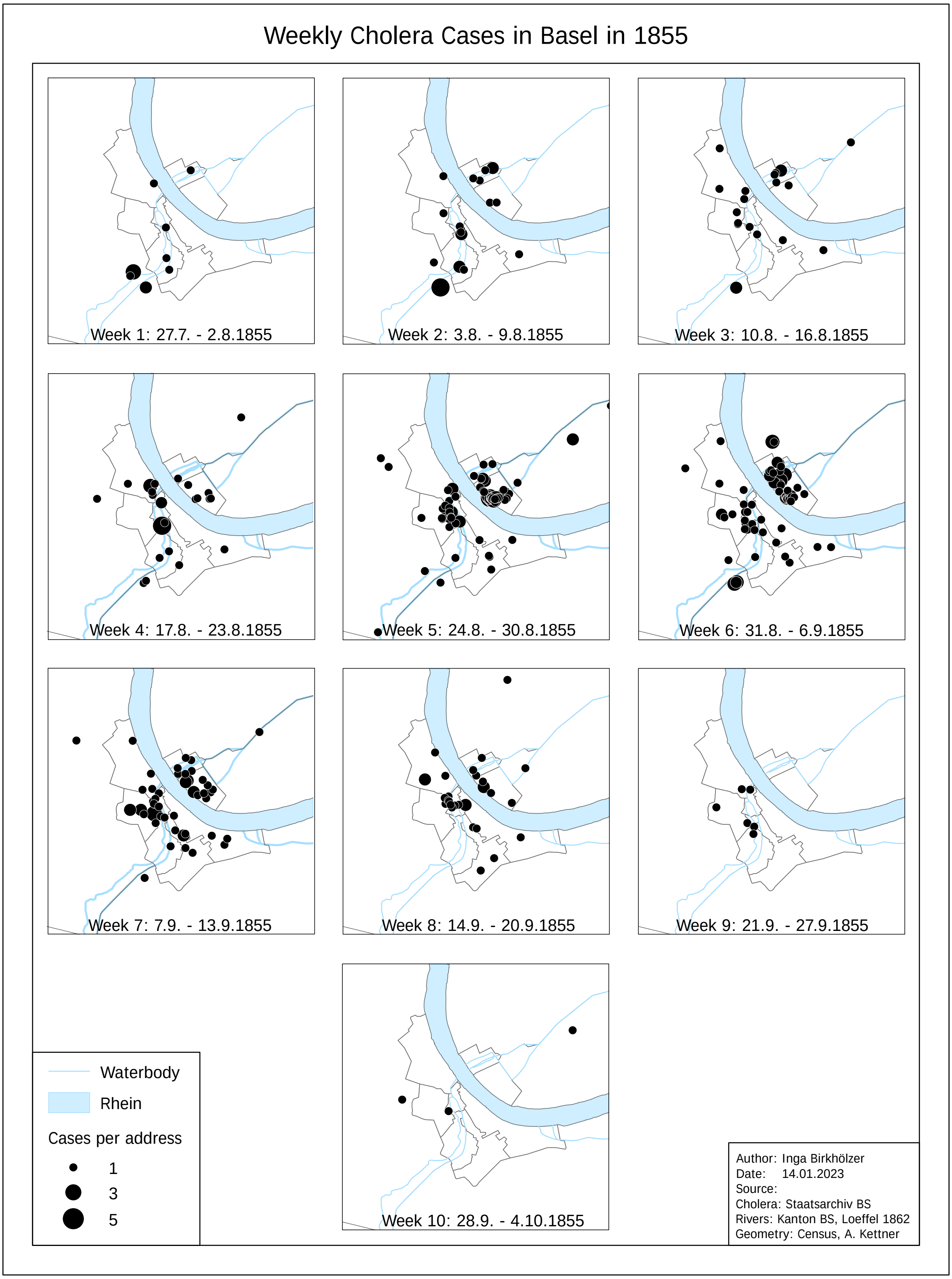


Figure 4.11: Time series of new cholera cases per week in Basel, 1855.

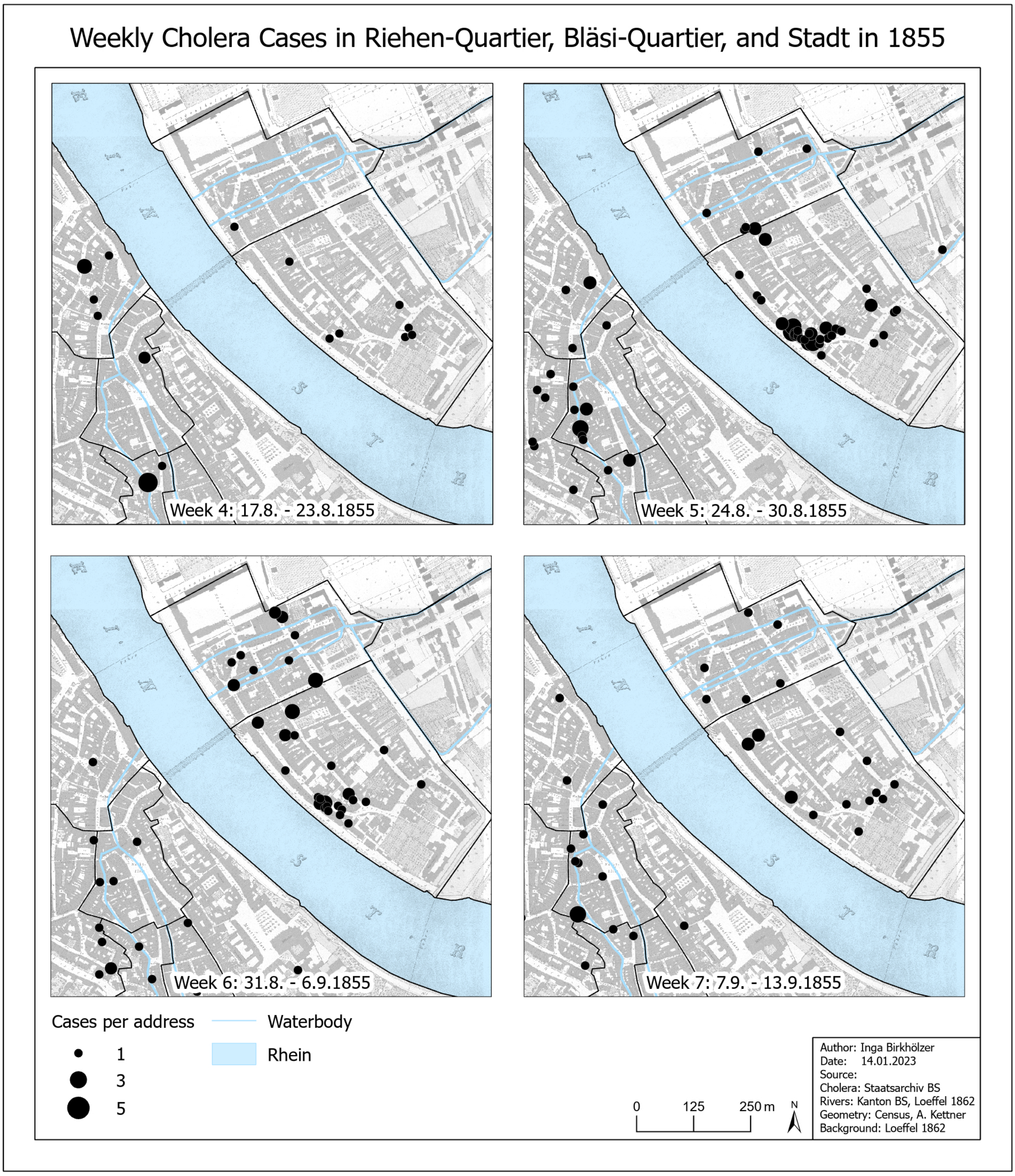


Figure 4.12: Time series of new cholera cases per week in urban Kleinbasel and Stadt district, 1855.

4.5 Potential influencing factors

4.5.1 Wells

To investigate whether and how sources of drinking water could possibly play a role in the spread of cholera, wells that were assumed to be publicly available were considered. The map of the wells with their respective Thiessen polygons can be seen in Figure 4.13. Again, the highest cholera case densities were found in Kleinbasel in the perimeter of the wells in *Rheingasse*, where 56 cholera cases fall into the perimeter of the respective source of drinking water. The high absolute case count and the small area size of this Thiessen polygon result in the highest case density of 5,921 cases per square kilometer. For the nearest well from there, at *Lindenberg*, 13 cholera cases were counted within its respective Thiessen polygon, resulting in a case density of 758 cholera cases per square kilometer.

In general, case densities in urban Kleinbasel are rather high in comparison to Grossbasel. This pattern matches that of Figure 4.9. In Grossbasel, high cholera densities per square kilometer occur mostly near the Birsig river. Second highest absolute case counts (n=22) and case densities (1001 cases per km^2) are found in the polygon where the Birsig and the Rümelinbach meet (see 3.4). However, low case densities can also be found for Thiessen polygons that touch the Birsig, which is the case for mostly higher-elevated river sections. To get an overview of the terrain, see Figure 3.4. The terrain can be seen in the next section in Figure 4.14.

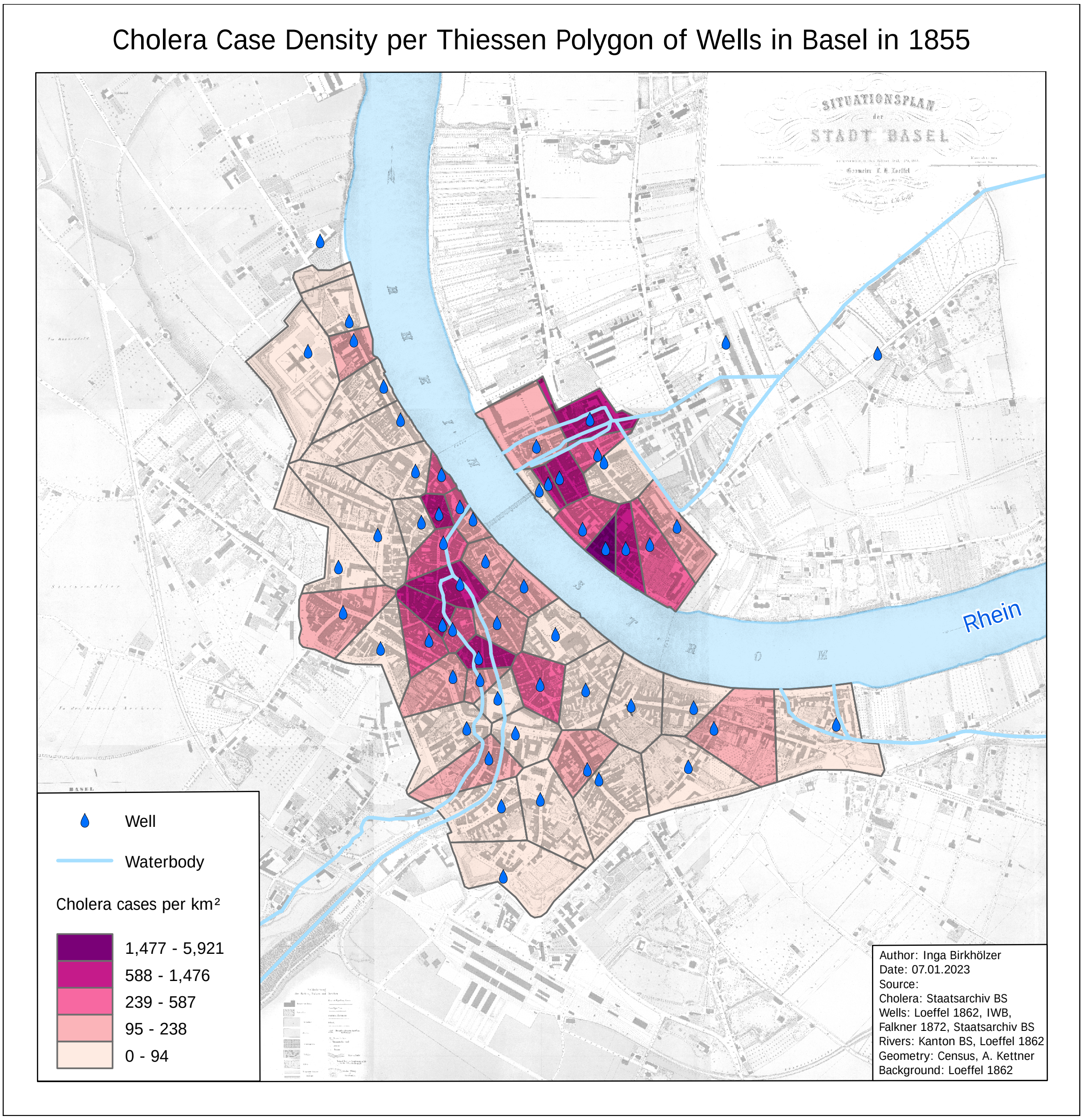


Figure 4.13: Cholera cases density per Thiessen polygon based on well location in Basel, 1855.

4.5.2 Geographic characteristics

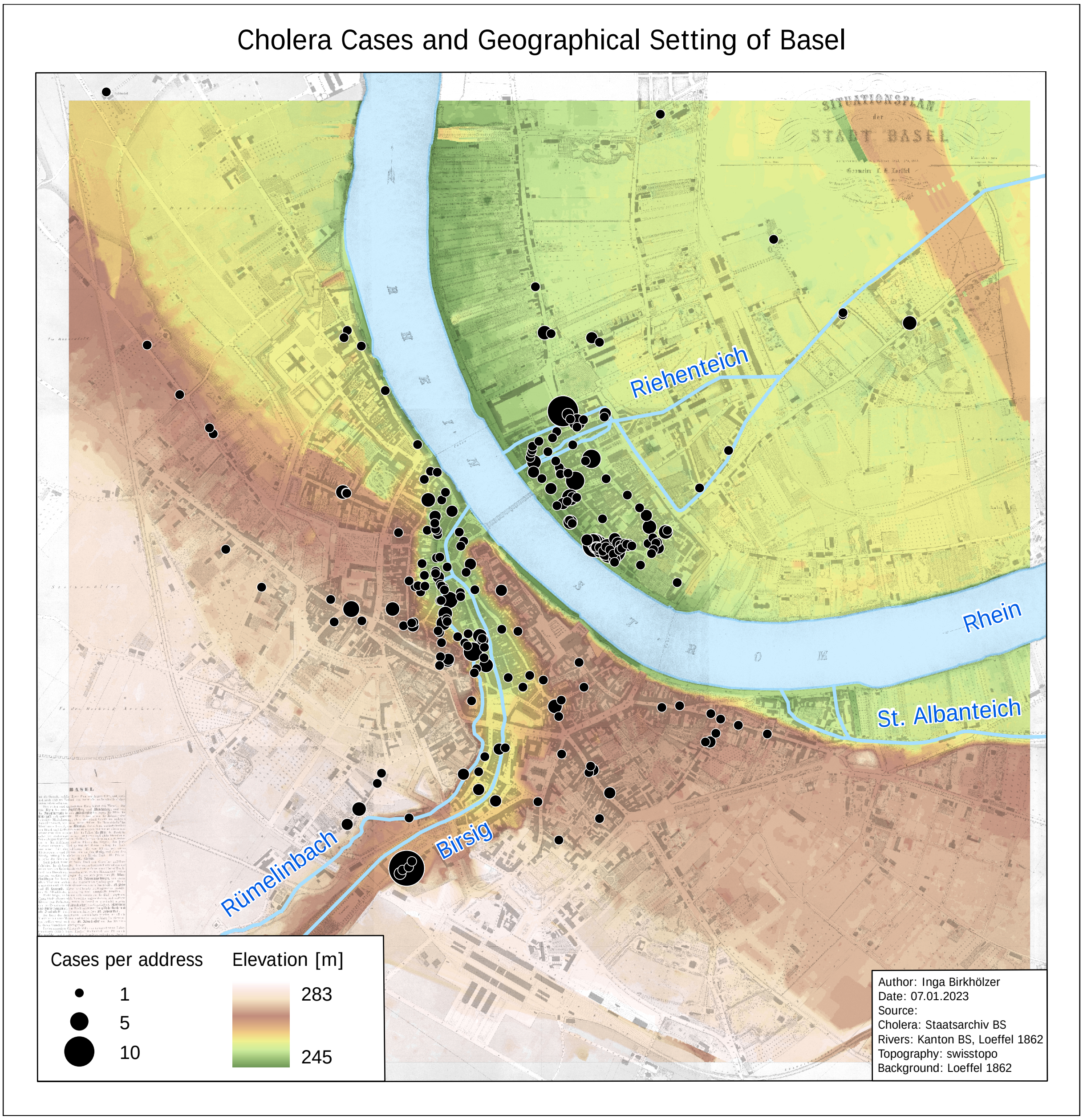


Figure 4.14: Cholera cases in relation to geographic characteristics of Basel, 1855.

The geographical setting of Basel is characterized by both waterbodies and topography. The river Rhein divides the city into Grossbasel on the south-eastern riverside and Kleinbasel on the northwest. At the time of the outbreak, only one bridge connected the two parts of the city. The second important river of Basel is the Birsig, and its river course is strongly related to the topography in Grossbasel, as over time, it has formed the Birsig valley, which becomes apparent when looking at the elevation in Figure 3.4. Coming from the southwest and flowing north, finally emptying in the Rhein, the Birsig river forms a seemingly flat plain inside the valley. The river plain itself is rather uniform in elevation and in width. Both valley sides are steep with strong vertical differences in height at small horizontal distances. The edge of the Birsig valley and its adjacent elevated plains show similar elevations.

Additional waterbodies depicted in the Situation map include the Rümelinbach, a canal coming and flowing parallel to the Birsig, the St. Albanteich dyke, a canal with water from the river Birs in the east, and the Riehenteich dyke with its branches in Kleinbasel. These dykes were used industrially.

In the northeast of the map, the brown-colored more elevated section represents the railway station *Basel Badischer Bahnhof* and its corresponding rail tracks. The location of this railway station and its elevation does not represent that of the historic *Basel Badischer Bahnhof*, which is situated further to the west, as can be seen in the Situation map of 1862 in Figure 2.3 or in the background of Figure 3.4.

Grossbasel Looking at the cholera case distribution in comparison to both topography and river course, it is striking how in Grossbasel, most cholera cases are located in the Birsig valley at a low altitude. Comparatively few cases occur in the more elevated parts of Grossbasel. The proximity of the cholera cases to the Birsig and the Rümelinbach is prominent. However, a lot of the cases are situated at the left riverside and at the bottom part of the western side of the Birsig valley. Fewer cases are located on the right side of the Birsig.

Kleinbasel The terrain in Kleinbasel appears rather uniform, with the lowest elevations near the Rhein, increasing slowly towards the northeast. Due to the even terrain, no clear pattern can be found in terms of cholera case locations and topography. Cholera cases are again mostly located within the inner-city parts of Kleinbasel.

The branches of the Riehenteich canal are close to the several cholera cases in the north-western part of Kleinbasel (*Bläsi-Quartier* district). However, the highest case numbers occur in *Rheingasse*, where no canal flows nearby.

4.5.3 Societal circumstances

Number of people per address With including information on the living standard and demography in the census data of 1850 and 1860, cholera incidences were opposed to social indicators on the district level. For this, bivariate maps of the districts' cholera incidences and the number of people living at one address or in a household, respectively, were brought together qualitatively in form of bivariate maps.

The bivariate map in Figure 4.15 depicts the cholera incidence and the median of the number of people living at the same address, aggregated to the district level.

The average median numbers of people per address vary between 12.5 and 23.5 people. For the urban Kleinbasel districts *Riehen-Quartier* (23.5 people per address) and *Bläsi-*

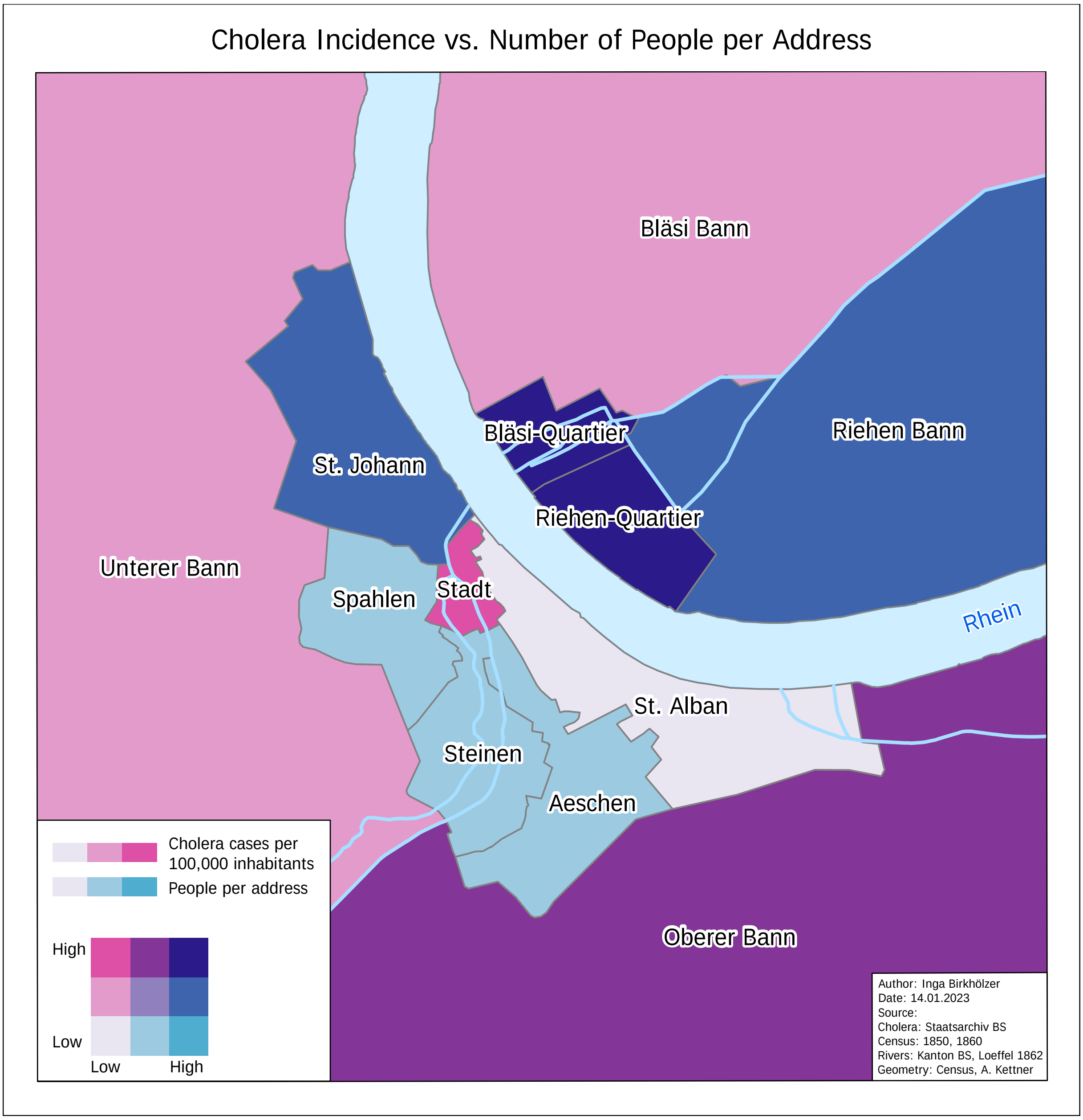


Figure 4.15: Cholera incidence vs. the number of people per address.

Quartier (20 people per address), both cholera incidences and the number of people per address are high. The two rural Kleinbasel districts show mid-range incidences, whereas the *Bläsi Bann* comprises low (14.5 people per address) and the *Riehen Bann* high (18 people per address) numbers of people per address.

In urban Grossbasel, the *Stadt* district shows a high cholera incidence with a low (15.5 people per address) number of people per address. *Spahlen*, *Steinen*, *Aeschen* and *St. Alban*, cholera incidences were low with a low to mid-range number of people per address (17, 17.5, 15.75, and 13, respectively).

Household size The distribution of cholera incidences and the number of people per household is shown in Figure 4.16. The average median numbers of people per household vary between six and eight people.

The districts *Riehen-Quartier*, *Bläsi-Quartier* and *Stadt* that show the highest incidences (see Figure 4.8), show mid-range numbers of people per household.

In the *Oberer Bann* district in rural Grossbasel, both cholera incidence and the number of people per household are high. The other *Bänne* districts show mid-range cholera incidences and mid-range to high numbers of people per household.

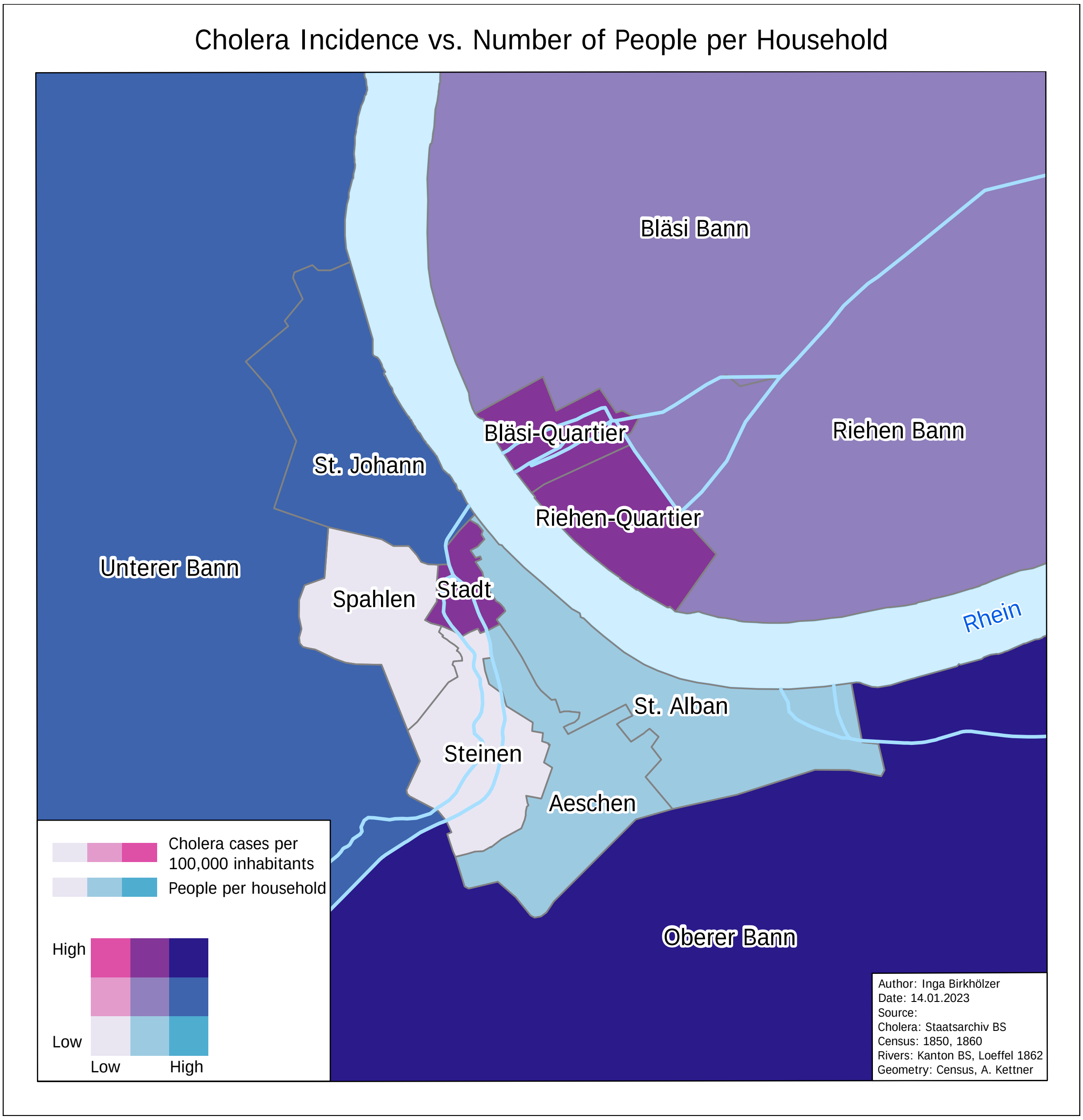


Figure 4.16: Cholera incidence vs. the number of people per household.

The spatio-temporal pattern was shown in Figure 4.11 and 4.12, with weekly point distributions of Basel over the whole course of the epidemic, and a focus on the *Riehen-Quartier*, *Bläsi-Quartier*, and *Stadt* districts during the height of the epidemic, respectively.

Kleinbasel was affected the most severely during a period of two weeks (24.8.- 6.9.1855), with 105 of the 164 cases. In Grossbasel, the disease spread predominantly in the inner parts of the city with a less clear temporal pattern, as seen in Figure 4.10.

5 Discussion

5.1 Digitization of historical archive data

Following the initial research question **Q 1.1: How can historical data on the cholera epidemic in Basel 1855 be processed for further digital use?**, cholera case data from the Staatsarchiv Basel-Stadt were digitized manually and geocoded using the methods described in Section 3.1.1. The localization of place names (toponyms), e.g. street names and numbers that were used for the geocoding, is a subject in the realm of Geographic Information Retrieval, where issues such as the disambiguity of toponyms can be an issue (Purves et al. 2018). The meaning of a toponym, e.g. the coordinates of a specific house's address or the extent of a district in Basel, can – and in this case did – change over time and has to be adressed to preserve historical correctness.

In turn, also previously digitized historical data were used in this thesis, e.g. the census data from the years 1850 and 1860 and the Situation map from 1862. A central aspect of making the cholera case data accessible was setting up the GIS project, where all datasets were collected and brought together. This enabled data exploration by stacking different data layers and generating maps and graphs. With the subsequent publication, the data can be used for further research. In this thesis, the English language was chosen to make research outcomes available to a wider language space, as previous research on this epidemic was conducted in German.

Implication of digitization With the digitization of historical archive data, this thesis contributes to the preservation of data by bringing it into the digital age of the 21st century. With the trend toward research based on digital sources, analog sources are at risk of being left behind. Digitization and data processing are bound to a high expenditure of time. Additionally, also know-how is needed for deciphering hand-written tables or unstructured notes into machine-readable form. The ongoing improvement of applications and also advances in machine learning facilitate the accessibility of these data sources (Baydoun et al. 2019). Even though digitization gets more feasible, sources can only be used if they are known and stored in repositories in a way that people can find the source of interest, ideally in a digitally accessible database. Further, sources must be considered to be eligible for digitization, which raises the question of what purpose possible digitization serves, e.g. digitizing for the sake of preserving the source and a persisting existence, or for specific use (Gertz 2011). With the choice of digitizing and making historical data available, this thesis contributes to the movement of Open Science.

Open Science The University of Zurich follows an open science approach by making research, data, and methods accessible to the public (Hermans et al. 2011). The movement aims at facilitating and improving research practices, e.g. in terms of transparency, reuse, reproducibility, or the prevention of redundancy in data (Hermans et al. 2011).

5.2 Visual reconstruction of the 1855 cholera epidemic in Basel

The reconstruction of the cholera outbreak was done by visualizing the spatial and spatio-temporal patterns. Following, the respective research questions Q 2.1 and Q 2.2 are answered.

Q 2.1: What kind of spatial pattern do the cholera cases in Basel 1855 show? The distribution of the cholera cases varies throughout the city, where the districts *Riehen-Quartier* and *Bläsi-Quartier* in urban Kleinbasel on the northern side of the Rhein were affected most severely by cholera. In Grossbasel, mainly the inner city in the Birsig valley showed a high accumulation of cholera cases. Setting these results into relation to previous literature, the historical reports of De Wette (Ludwig De Wette 1856) and the cholera commission (L. De Wette, Heimlicher, and Bischoff 1856) draw a similar picture to this thesis' results regarding the spatial distribution of the cholera epidemic in Basel 1855. With its numerous tables, e.g. the list of cholera case numbers and cholera deaths per district, the outbreak is described spatially (Ludwig De Wette 1856). Yet, the sole indication of district names can only be interpreted geographically if a district's respective geographical extent is known. This can be achieved by having spatial knowledge about the city of Basel, as in the case of Dr. De Wette (1856), or by the creation of district geometries and a subsequent depiction on a map, as seen in this thesis. For this, the local knowledge of Andreas Kettner, in correspondence to his knowledge of historical Basel at the time, facilitated the generation of the historical district extent.

Deviation of cholera case numbers on district level Deviations between De Wette's cholera report (Ludwig De Wette 1856) and this thesis regard the numbers of cholera cases per district, especially in Kleinbasel. The question of what area a certain toponym refers to, in this case a district name, is essential. In this case, the extent of a district was used to make statements on the severity of the cholera outbreak on district levels. This comprised both the absolute number of cholera cases, as well as the relative case number in comparison to the background population (incidence). Regarding the geometric extent, the area can change, leading to other outcomes in terms of case density. Depending on where borders are drawn, the outcome of a study can vary. On the other hand, administrative units may not represent neighborhoods in a sense of social units (Santos, Chor, and Werneck 2010). This finding is not new and was addressed in De Wette's report (Ludwig De Wette 1856). For example, De Wette's understanding of the inner-city represented a more extensive area than the administrative unit *Stadt* of the census, whereas the surrounding inner-city districts were condensed to *Vorstädte* (suburbs) or *Äussere Stadt* (outer city). This classification was assigned in the list of cholera cases, as seen in Figure 3.2. De Wette's aggregation of the cholera cases into these boroughs is depicted in Figure 5.1. These boroughs may be more coherent within their borders due to more similarities regarding social aspects, and also cholera cases may be more evenly distributed within these units. However, this geometry cannot be set in relation to the census data at the district level.

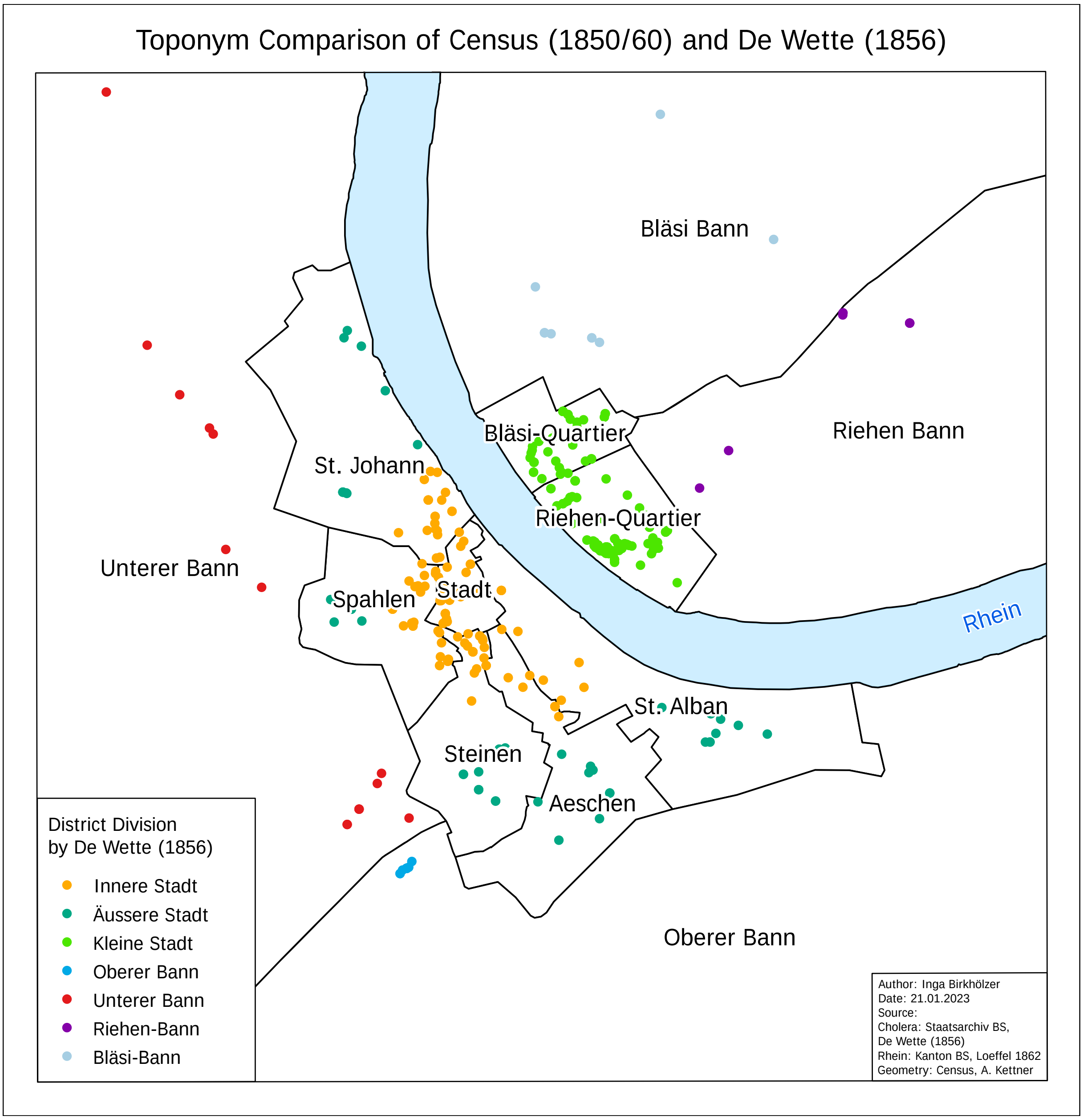


Figure 5.1: Toponyms for different areas parts of Basel, referring to the cholera case location in Basel, 1855 by Ludwig De Wette 1856.

Modifiable Area Unit Problem The aggregation of data to different levels is a familiar issue in geographic information science and is also known as MAUP (Modifiable Area Unit Problem) (Buzzelli 2020). Changes in geometry, i.e. the size, shape, and orientation yield consequences and change the perception of the mapped data (Buzzelli 2020). This issue has also been addressed in relation to incidence rates (Nakaya 2000). In this thesis, MAUP was visible in the cholera case density of a certain area, i.e. whilst comparing the densities based on districts and the Thiessen polygons around the wells. In addition to this, the aggregation of data in e.g. choropleth maps yields the risk of ecological fallacy if assumptions made on one scale are transferred to another (Buzzelli 2020).

Q 2.2: How does the spatial pattern vary throughout the course of the epidemic? Regarding the spatio-temporal pattern, the Kleinbasel and Grossbasel differ from each other. Kleinbasel was affected the most severely during a period of two weeks. In Grossbasel, the disease spread predominantly in the inner parts of the city with a less clear temporal pattern, as seen in Figure 4.10. These statements regarding the spatio-temporal pattern of the outbreak are qualitative and for a clearer statement about the cholera hotspots at certain times, further statistical evaluations, e.g. using SaTScan (Kulldorff et al. 2005) are needed. With the advance of these newer analysis methods, these patterns can give new insights into the course of cholera epidemics, among other infectious diseases, as could be seen in the spatio-temporal analysis of the cholera outbreak in Haiti in 2010 (Gaudart et al. 2013).

Regarding past epidemics, more thorough analyses of other cholera outbreaks of the era may enable a future comparison of the respective disease dynamics to investigate similarities and differences.

5.3 The role of influencing factors in the spread of cholera

Q 3.1: What factors potentially influenced the spreading of cholera? With the aim of explaining the patterns described above, this thesis included the location of public wells (Figure 4.13) and the geographic setting of Basel (Figure 4.14). Additionally, the incidences were set in relation to the average living situation per district, represented by the number of people per household and address, respectively.

Wells Just as with the cholera case density map (Figure 4.9), the Thiessen polygon map of the wells (Figure 4.13) should be looked at cautiously, as the case density per area does not take into account the actual background population size, i.e. polygons with large unpopulated spaces may be underestimated and densely populated areas in the heart of the city may be overestimated in terms of case density. However, this map can give an insight into which wells could play a role in spreading cholera by being contaminated, as well as which wells presumably did not have an influence. One can argue that Thiessen polygon areas with low cholera case densities did not have a problem with their respective source of drinking water.

The only hint in discussed historical sources regarding the contamination of drinking water wells was found in the cholera report by the cholera commission of Basel (L. De

Wette, Heimlicher, and Bischoff 1856, p. 96). Without a statement of the chronology regarding the shutdown of the well at *Rheingasse*, it remains unknown whether it was closed immediately during the cholera epidemic after contamination was considered to be possible. Provided that this was the case, further cholera cases could be prevented. Looking at the temporal distribution around the respective well on *Rheingasse* (see Figure 4.12), cholera case numbers were highest in week 5 and decreased on a high level in week 6, followed by lower numbers in week 7.

However, just as with John Snow and the removal of the Broad Street Pump handle, the epidemic might have followed its general course, having already passed its zenith on the *Rheingasse* in Kleinbasel. On the other hand, the adjacent *Bläsi-Quartier* was affected the most during week 7. In the report of the cholera commission, the potentially contaminated well was only mentioned once, whereas the cholera report by Ludwig De Wette never addressed this issue. Hence, one can argue that the importance of this well and the role of drinking water was not fully recognized, not least owed to the prevailing paradigm of disease transmission (Haefliger 1984).

Geographic setting The cholera cases in Grossbasel were mainly located in the Birsig valley, which was also noted in the historical sources (Ludwig De Wette 1856,L. De Wette, Heimlicher, and Bischoff 1856). Due to the strong connection between topography and river courses, the two phenomena cannot be distinguished clearly to determine one or both as an apparent factor in cholera transmission. The hygienic situation of the Birsig river was also addressed. From a disease transmission point, it is possible that the Birsig river was contaminated with cholera, e.g., due to sewage being disposed into the river. However, for an infection, the pathogen must be ingested orally. The filthiness of the Birsig river was known to the public and the authorities, and therefore the Birsig river might not have been used as a source of drinking water.

De Wette (Ludwig De Wette 1856) also notes that the left riverside was affected more heavily, which is also apparent in Figure 4.14. He draws a connection to the steep slope of the valley and that a pit latrine could have played a role, with fluid flowing downhill and infiltrating water at lower elevations (Ludwig De Wette 1856, p. 38). Yet, this phenomenon would only explain certain cholera cases, while the majority of the cases in Grossbasel still lie in proximity to the Birsig river. Hence, the influence of the Birsig river cannot be excluded, especially regarding recent studies stating river proximity to be a risk factor in the spreading of cholera, along low elevation (X. Wang and Yang 2021, Luque Fernandez et al. 2012).

Sewage An additional factor in disease transmission, regarding the geographic aspect and the drinking water wells, is sewage disposal. With cholera being transmitted over the fecal-oral route (World Health Organization 2022), the handling of sewage is crucial in the containment of the disease. The historic report (Ludwig De Wette 1856, p. 37) quotes two ways of sewage disposal prevailing in Basel at the time of the epidemic in 1855: Pit latrines (*Abtrittgrube*) and latrine gullies (*Abtrittdole*). However, despite general statements about where these ways of sewage disposal were prevalent (pit latrines in suburban *Vorstädte* and gullies in the Birsig valley of the inner city), only a few individual pit latrines were discussed, e.g. on *Adelberg / Nadelberg* or near *Steinenthor* (Ludwig De Wette 1856, p. 37). Due to this lack of information, no extensive verification of De Wette's statements could be made, although his assumptions seem plausible. Yet, the role of pit latrines or latrine gullies remains unclear in the case of Basel in 1855.

Societal circumstances To grasp a general overview of the living situation in each district in relation to the cholera incidences were depicted using the number of people per address and household. In urban Kleinbasel (*Riehen-Quartier* and *Bläsi-Quartier*), where the highest cholera incidences were found, the number of people per address was high, whereas the number of people living in a household was medium.

The digitization of individual cholera cases with information on name, age, sex, and profession can give valuable insight into the societal circumstances of the infected people. The information in the census data from 1850 and 1860 can furthermore be used to set these attributes into the context of the background population. However, this methodology exceeded the scope of this thesis, which aimed at looking at visualizing the cholera outbreak using cartography.

Relevance of risk factors today With cholera still being prevalent in various countries, it is crucial to be aware of factors that contribute to the spread of cholera (World Health Organization 2022). Current data on these cholera outbreaks facilitates the research in affected regions, and geospatial analysis can be used to identify clusters in the spatial pattern of the disease and possibly related risk factors (Bi et al. 2016). By addressing risk factors on a small scale, according measures in disease prevention can be taken (X. Wang and Yang 2021).

5.4 Limitations

This thesis has its limitations. Following, the main limitations are assessed and should be kept in mind, especially in case the created data is used for further research.

Limitations in data De Wette's report (1856) indicates that the available collection of cholera cases may be incomplete (Ludwig De Wette 1856). The main critique that is noted is that only severe cases of cholera were reported (Ludwig De Wette 1856, p. 25). Today, it is known that most people infected with cholera do not develop any symptoms, and severe symptoms show only in a minority of people that have symptoms (World

Health Organization 2022). With the case fatality ratio of 52 % (197 of 382 infected people died) and the fact that only a small fraction of infections are symptomatic, the actual number of cholera cases in Basel in 1855 is very likely to be much higher. This impact might be even more severe, with De Wette stating that not all cholera cases were reported to the authorities, despite that being mandatory (Ludwig De Wette 1856, p. 25). It is possible that this initial underreporting, provided that this was the case, distorted the outcome of this thesis, although the extent of this distortion is unknown and remains uncertain. Especially if physicians in certain parts of the city did not report the cholera cases known to them, some regions might be systematically more underreported than others. However, according to the disease prevention methods targeted at specific areas (e.g. the *Rheingasse*, as seen in (L. De Wette, Heimlicher, and Bischoff 1856, p. 18), other disease hotspots might not have been able to fly under the radar of the general public and authorities. This limitation was unavoidable due to the availability of this historical data.

Methodological limitations Concerning the digitization and data preparation process, the manual deciphering of hand-written sources yields the risk of misreading and an incomplete reproduction of the source, as not every record was readable. Emphasis on correctness was put into the decipherment of toponyms, which ensured the quality of the geocoded data. However, records on other attributes such as name or profession may be incomplete.

Since the data processing was done in a geographic information system (ArcGIS Pro), occurring inconsistencies in data were corrected within the application. The continuous steps taken to improve the datasets and their attributes can therefore not be reconstructed as clearly as it would have been possible using a code-based approach. This trade-off regarding transparency was however put up with to improve the quality of the datasets, which was mostly done manually. The immediate, visual response of a GIS was preferred in this case, not least as the data collection and processing was primarily explorative.

Concerning cartographic visualization, the results come in a form of static maps, which is owed to the format of this thesis, i.e., a static file in PDF format. In this case, static maps displayed the processed data in a fixed, preferably interpretable, but curated way. Curated in a way that only a small portion of the datasets' attributes are visible and was chosen to serve the reconstruction of the cholera outbreak in Basel in 1855, which was a goal in this thesis.

5.5 Implications

The digitization of historical sources, such as analog archive data, is an inevitable step in bringing them into the digital age. With the digitization of historical material, past events can be revisited with a modern understanding of disease transmission. The digital reconstruction of the cholera epidemic in Basel in 1855 contributes to recent efforts in the reappraisal of historical, 19^{th} century collections of analog sources, i.e. the digitization of the census data of the year 1850 and 1860 in Basel, or of the excavation of the hospital cemetery. These projects were facilitated by the citizen science project Basel Spitalfriedhof (Hotz, Schumacher, et al. 2015, Hotz, Zulauf-Semmler, and Fiebig-Ebneter 2016). The creation of the district geometries of Basel during that era had not been done before, made it possible to visualize the census data spatially, and can be used for future research beyond cholera.

Addressing cholera research, this work is the first to make the cholera outbreak in Basel accessible to an English-speaking audience. Understanding past epidemics and pandemics and their respective disease transmission factors can help deal with contemporary diseases (Staub, Jüni, et al. 2021). Taking different social, topographic, or infrastructural aspects into consideration can give new insights into previously unknown disease patterns, which could be seen in the case of John Snow (Koch and Denike 2009).

6 Conclusion

6.1 Summary

This thesis reappraised the cholera epidemic in Basel in 1855. The aim was to digitize historical cholera cases and geocode the respective case locations. The spread of the cholera pandemic was set in the context of where cases occurred, how they stand to the background population, area density, distribution of water wells, environmental factors such as topography and water bodies, and societal factors such as household size. This contextualization was performed by visualizing cholera cases and potential influencing factors using geographic information systems and visualization. The resulting maps were used to get a visual understanding of the outbreak and to assess historical reports regarding how the outbreak was experienced at the time. These reports revealed that even though the cause of cholera was not known, the authorities identified the areas at risk to be at low elevations near rivers (Birsig in Grossbasel) and near potentially contaminated sources of drinking water (well on *Rheingasse*). These patterns are visible in the maps this thesis shows, and contemporary research on cholera backs these ways of disease transmission (X. Wang and Yang 2021, Luque Fernandez et al. 2012).

6.2 Future work

This work laid the foundation for further analyses concerning the cholera epidemic in Basel in 1855. With the data that was worked up during this thesis, other spatial analyses can be performed, e.g., with the use of SaTScan (Kulldorff et al. 2005), space-time permutations (Stojmanovski 2018) or network Kernel Density Estimations based on, e.g., the street network (Lee 2018). Statistically, more precise statements about the background population can be made by assessing the census datasets of 1850 and 1860 on the level of individuals by geocoding every address and hence every residence's location rather than using data aggregated to the district level. Further, the available data can be used for survival analysis (Cox regression), assessing the survival time regarding potential influencing variables such as age (Ziegler, Lange, and Bender 2004). Additionally, the well-documented historical reports of the epidemic in Basel in 1855 could be geoparsed (extraction of location names in written text) and assigned to coordinates to systematically examine what areas of the city were of particular interest at a specific time in the reports. Moreover, available information on cholera cases, e.g., the profession or distribution of surnames throughout the city, can give an insight into the social relations of the infected and serve as a form of contact tracing (short-cycle transmission, as seen in Phelps et al. 2018).

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Personal Declaration

I hereby declare that the submitted Thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the Thesis.

Inga Birkhölzer Wildhaus, 28.01.2023